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THE HELIOMICROMETER[1]

By GEORGE E. HALE

The measurement and discussion of photographs of the sun made with the spectroheliograph involve a large number of processes, some of which have been satisfactorily worked out, while others are still under consideration. Up to the present time special attention has been devoted to the following points:

1. The measurement of the heliographic positions of flocculi, with reference to the determination of the solar rotation.

2. The measurement (with the monocular micrometer of the Zeiss stereocomparator) of the relative distances from the center of the sun of corresponding points in the calcium (H_2) and hydrogen ($H\delta$) flocculi, with reference to the relative level of these objects.

3. Comparative studies, with the same instrument, of the forms of flocculi, as photographed with various lines.

4. Photometric determinations of the relative brightness, at various distances from the sun's center, of the flocculi and the adjoining photosphere, as bearing on the level of the flocculi and the absorption of the solar atmosphere.

5. Photometric measurements similar to (3), but especially adapted for the determination of the level of sun-spots.

6. Stereoscopic studies of the flocculi.

7. Studies of the flocculi with a kinetoscope, with reference to their changes in form.

[1] *Contributions from the Solar Observatory*, No. 16.

8. The measurement, by a photometric method, of the areas of flocculi in regions ten degrees square, for the study of variations in the solar activity.

Spectrographic studies have also been made, particularly of the hydrogen and calcium lines, for the purpose of interpreting the spectroheliographic results.

The present paper deals with the measurement of heliographic positions; the other methods of measurement and reduction will be described later.

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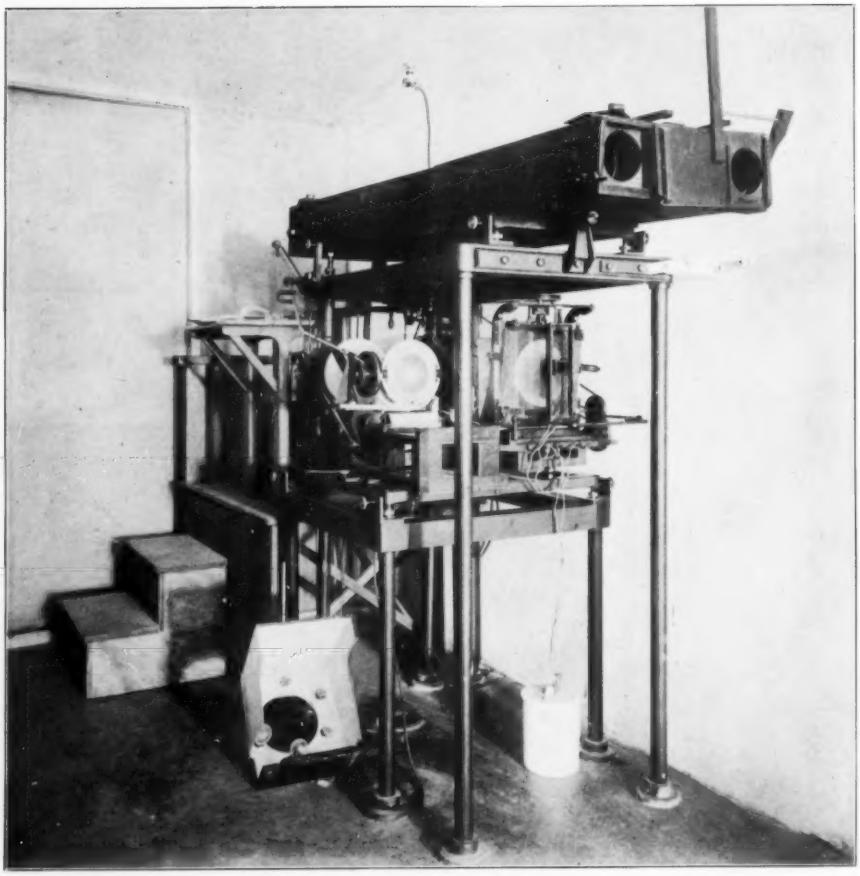
The determination of the heliographic positions of sun-spots, as carried on at Greenwich, involves the measurement of their polar co-ordinates, and a simple calculation, facilitated by the use of tables. As the average number of spots on each photograph is small, only a moderate amount of computing is required, and the method has apparently proved satisfactory after many years of service. For the flocculi the case is different. The average number of flocculi suitable for measurement on a single plate may reach forty or fifty, thus involving a large amount of computing in the aggregate. Furthermore, the lack of sharpness of the flocculi (as compared with spots), and their rapid changes of form, rarely permit of the precision of setting attainable in the case of spots, and render a different mode of measurement feasible. It will appear, however, that in its perfected form the instrument described in this paper is capable of giving results no less precise than the ordinary measuring machine.

The first and simplest form of the instrument, which I devised for the measurement of the Kenwood spectroheliograph plates by Mr. Fox at the Yerkes Observatory, consists of a metallic globe, with smooth white surface, upon which the solar image is optically projected. The axis of the globe being set at the inclination required by the date of the photograph, and the plate properly oriented, it is only necessary to read off the heliographic latitudes of the flocculi and their differences in longitude from the sun's center, by the aid of parallels and meridians ruled, one degree apart, on the surface of the globe. The results obtained with this simple device were so satisfactory that it is still regularly employed in the measurement

PLATE XVII



THE HELIOMICROMETER

of the Rumford spectroheliograph plates. The essential condition to be met is that the angular diameter of the globe, as seen from the projecting lens, shall equal the angular diameter of the sun, as seen from the earth.[1]

In the second form of the instrument, as constructed in the shops of the Solar Observatory, two 4-inch (10 cm) telescopes were mounted parallel to one another. One of these pointed at a globe, 60 feet (18.29 m) distant, beside which stood the solar photograph to be measured, with its center in the optical axis of the other telescope. The images of globe and plate, as formed by the two telescopes, were brought together in a single eyepiece, by means of a half-silvered prism. After the photograph had been oriented and centered on the globe, by adjustments controlled from the observer's seat, the latitudes and longitudes of the flocculi were read off with respect to parallels and meridians, ruled one degree apart, on the surface of the globe. This instrument gave good results, but the illuminated surface of the globe (black lines on a matt silvered surface) interfered with the visibility of the minute flocculi. Experiments with cross-hairs for setting purposes, and the desire to secure a higher degree of precision than estimates to a tenth of a degree could afford, soon led me, by successive steps, to the design embodied in the "heliomicrometer," which is illustrated in Plate XVII.

The two 4-inch telescopes, of 60 inches focal length, which were used in the second form of the instrument described above, are retained and mounted immediately above the globe and the plate-carrier. These telescopes point to the centers of two optically plane mirrors, mounted on a concrete pier at a distance of about 30 feet (9.14 m) In the telescope on the right, the solar image, brilliantly illuminated by transmitted light, is seen after reflection from one of the plane mirrors. In the same way the globe, illuminated by reflected light, may be seen in the telescope on the left. The images are brought together in a single eyepiece, with the aid of a right-angle prism at the end of each telescope and a half-silvered prism, similar to that used in the monocular eyepiece of Zeiss's stereocomparator, mounted a short distance in front of the eyepiece.

[1] A full description of this instrument will soon appear in a paper by Mr. Fox and myself on the solar rotation.

As a complete description of the apparatus will be published later, only its general features are described in the present paper. The adjustments of the plate-carrier permit the photograph to be raised or lowered, moved right or left, rotated for orientation, and moved toward or from the mirror. Cross-hairs, mounted immediately in front of the plate,[1] are controlled from the eyepiece, and their intersection can be made to coincide with the flocculus to be measured. While settings are thus being made, the object-glass of the telescope which points to the globe is covered by a swinging shutter, controlled by the observer. Under these conditions the details of the solar photograph are seen with great clearness, and settings are made as easily and rapidly as in any form of measuring machine.

The entire globe has a matt silvered surface, and one hemisphere shows no lines except the equator and central meridian. These lines do not quite reach the center of the globe. At the point where they would intersect, a small circular black dot is engraved. This is brought into coincidence with the intersection of the cross-hairs, by rotating the globe in longitude and latitude. In longitude the globe has both quick and slow motions, permitting a rapid and accurate setting to be made. In latitude a single motion, consisting of a worm-gear operated by an arm with double Hooke's joint, gives sufficiently rapid motion, combined with perfect control. The longitude circle, provided with a vernier reading to tenths of a degree, or, if desired, to 2′, is read with a telescope from the eye-end. The globe is then turned back to zero longitude, and at this point the latitude circle, also reading to tenths of a degree or to 2′, is read with a second telescope.

The vertical axis that carries the fork in the opposite bearings of which the horizontal axis of the globe rests, can be set at any desired angle, read by means of a vernier and divided circle. The inclination of this axis corresponds to the tabulated latitude of the center of the sun for the date of the photograph.

It is unnecessary to give here the details of the adjustments of the apparatus. It may be added, however, that the photographs made with the Snow telescope and 5-foot spectroheliograph are oriented by the aid of control plates, on which the solar image is allowed to

[1] The same support carries the electric pen, referred to below.

drift between two exposures. A line joining two images of the same flocculus gives the east and west direction. The angle between this line and a line drawn on the plate by the image of a needle-point mounted in contact with the collimator slit provides the means of orientation. The centering of the solar image on the globe is easily effected, with the aid of a metallic screen mounted in front of the globe and bearing a black circle, adjusted so as to be exactly concentric with the globe. This circle should coincide, when the instrument is in adjustment, with a black circle etched in a glass plate permanently fixed in the adjustable plate-carrier. This circle is slightly larger in diameter than the solar photograph which can thus be centered with great precision. In order to provide for the varying size of the image, due to the varying distance of the sun from the earth, the plate-carrier can be moved along rails, so as to change its distance from the telescope with which it is observed. The necessary adjustment of focus is made by moving the object-glass of the corresponding telescope.

Measurements are confined to objects within fifty degrees of the sun's center. This is for the purpose of avoiding errors inevitable when spots or flocculi are measured in the near neighborhood of the sun's limb. Furthermore, it is not necessary, within this limited region, to change the focus of the telescope used to observe the globe.

In testing the heliomicrometer, a photograph of the sun was measured with this instrument and with an ordinary measuring machine giving polar co-ordinates. After the reductions had been completed, it was found that the latitudes and longitudes of the flocculi, measured in the two ways, agreed within the limits of error of settings (one or two tenths of a degree). The operations of measurement proved as rapid with the heliomicrometer as with the other measuring machine, and all the time required for calculations was saved. A further test was made by measuring the positions of certain sun-spots, which also appear on the Greenwich photographs. Mr. Maunder was kind enough to give me the positions of these spots as determined at Greenwich. The results correspond within a few tenths of a degree, or as closely as could be expected under the circumstances.[1]

[1] The centers of spots on spectroheliograph plates are often slightly displaced by overhanging flocculi.

It should be stated here that Dr. Frank Schlesinger, with whom I had the benefit of discussing the first globe measuring instrument used at the Yerkes Observatory, suggested, in 1902, that an ordinary theodolite, provided with a small pointer in place of the telescope, might give good results in this work. The details of the apparatus were not worked out, and I had forgotten the suggestion, when I was led by the above described steps to the adoption of the same principle, namely, the use of divided circles in place of meridians and parallels ruled on a globe. This important element in the design is therefore due to Dr. Schlesinger. It is evident that a globe is not really required (as a pointer might suffice), but it has the advantage of permitting one surface to be divided into ten-degree squares, used as described below.

My attention has been called, by Professor A. E. Douglass, to his paper published in *Popular Astronomy* (**5**, 57, 1897), entitled "The Astronomer's Globe." This globe was used for the solution of spherical triangles. The positions of markings on *Mars* were also plotted on the surface of the globe, and their latitudes and longitudes read off with the aid of two divided semi-circles, which could be moved over the surface. The same, of course, could be done with sun-spots. I do not understand that any system of optical projection was used with this globe.

It will be readily seen that the heliomicrometer can be used as a stereocomparator (with monocular or binocular vision). For this purpose it is only necessary to mount in front of the globe a second photograph, illuminated by transmitted light. Miss Ware, who is in charge of the heliomicrometer, uses this arrangement for comparing the forms of the flocculi photographed on successive days, in order to select points suitable for measurement. By means of an electric pen, controlled from the eyepiece, a small dot is made on the glass side of the plate, for purposes of identification, near each point selected.

One hemisphere of the globe is ruled with meridians and parallels ten degrees apart. When seen in projection on the globe (the axis of which is given the proper inclination for the date in question), the intersections of the squares can be marked on the glass side of the plate by means of the electric pen. Plates marked in this way are used by Miss Smith in her photometric measures of the areas of

the calcium flocculi within ten-degree regions. The data thus secured are employed in our studies on the variation of the solar activity, with reference to the condition of the sun as a whole, and its activity in different zones of latitude and longitude.

The heliomicrometer could be improved by supporting all parts of the apparatus shown in Plate XVII on a stone or concrete pier. The present instrument, which is fastened to a concrete floor and braced to an adjoining brick wall, gives very satisfactory results, but is less stable than if it had been designed anew, instead of being modified from the second form of the instrument, described above. I am indebted to Mr. Pease for working out the detailed drawings.

In view of the rapidity of measurement, and the accuracy of the results obtained with this instrument, I can recommend it for the determination of the heliographic positions of spots and flocculi shown on direct photographs or on spectroheliograph plates.

APRIL, 1907

A PHOTOGRAPHIC COMPARISON OF THE SPECTRA OF THE LIMB AND THE CENTER OF THE SUN[1]

By GEORGE E. HALE and WALTER S. ADAMS

Prior to 1873, although the spectra of the limb and the center of the sun were compared by several observers, no differences in the relative intensities of the Fraunhofer lines were detected. In that year Hastings[2] noticed that some of the lines changed their appearance at the limb. In 1879 and 1880 he continued the investigation with improved apparatus. The results of the later observations, which were made visually with a Rutherfurd grating spectroscope, are given by Hastings as follows:

I. The most important fact of all is that the differences in the two spectra of center and limb are extremely minute, escaping all but the most perfect instruments, and all methods which do not place them in close juxtaposition.

II. Certain lines, the thickest and darkest in the spectrum, notably those of hydrogen, magnesium, and sodium, which appear with haze on either side, in the spectrum of the center of the solar disk, are deprived of this accompaniment in that of the limb.

III. Certain very fine lines (four observed) are stronger at limb.

IV. Other very fine lines (two or three observed) are stronger at center.[3]

Hastings, referring to the spectrum of sun-spots, remarks:

As is well known, such a spectrum exhibits a very strong general absorption, with a very slightly modified selective absorption. A few faint lines appear in the spot spectrum which are not otherwise seen; and a few faint lines of the ordinary spectrum are strengthened. A careful examination has persuaded me that the spectrum of a spot differs from that of the unbroken photosphere, just as the spectrum of the limb differs from that of the center of the disk, save that the variations are more pronounced.

In spite of the great interest and importance of these observations, they do not appear to have been repeated in the long interval which has elapsed since Hastings made them. A photograph by Jewell, reproduced in Young's *Manual of Astronomy*, page 221, shows that the H_1 and K_1 bands are greatly weakened at the limb, and this

[1] *Contributions from the Solar Observatory of the Carnegie Institution of Washington*, No. 17.

[2] *American Journal of Science*, **5**, 369–371, 1873.

[3] *Ibid.*, Third Series, **21**, p. 35, 1881.

effect seems to have been recognized by Deslandres in some of his papers, but we have seen no discussion of any other important changes from center to limb. In her *Problems in Astrophysics* (p. 42), the late Miss Clerke, after discussing various details of the Fraunhofer lines, writes as follows: "An embarrassing peculiarity of the Fraunhofer lines is their virtually uniform existence all over the sun's disk."

Our first photographic comparisons of the spectra of the limb and the center of the sun were made in the red region of the spectrum, mainly for the purpose of testing Halm's recent results regarding line displacements.[1] It was noticed at once that many of the lines on the plates showed slight changes of relative intensity, which promised to be of interest in connection with our sun-spot investigations. As the discussion in our last paper[2] indicates, we have been occupied with the problem of distinguishing between the changes in the appearance of lines produced by differences in temperature and by differences in the density of the vapors. In this connection, we had long since planned to take up an investigation of the spectrum of the limb as compared with the center of the sun. It was supposed, however, that the differences would be so slight that they could be detected only with difficulty, and a special means of testing suspected cases, by a photometric study of spectroheliograph plates made for this particular purpose, was devised. It will be seen from the results contained in the present paper that the differences, particularly in the more refrangible part of the spectrum, are so striking that no such device is required.

The photographs hitherto taken cover almost the entire length of the spectrum from λ 3600 to λ 7000. They were made with the Snow telescope and the Littrow spectrograph described in our previous papers on sun-spot spectra. The image of the sun on the slit has a diameter of about 6.7 inches (17.02 cm). The spectrograph is of 18 feet focal length and contains a 4-inch Rowland grating, having 14,438 lines to the inch (5700 lines to the cm). Most of the spectra were photographed in the third order, but some were taken in the

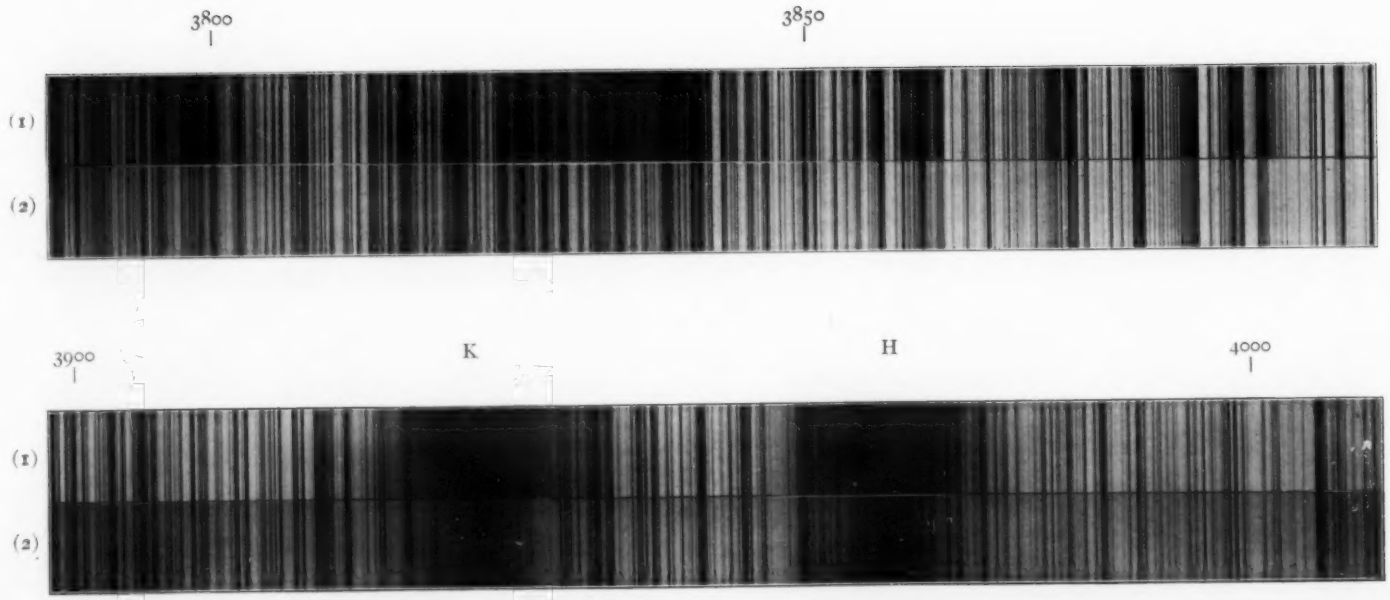
[1] *Astronomische Nachrichten*, No. 4146–47, **173**, 273, 1907.

[2] *Contributions from the Solar Observatory*, No. 15; *Astrophysical Journal*, **25** 75, 1907.

second, and a few in the fourth, the last for the study of line displacements. In making the exposures the image of the sun was adjusted so that the slit was parallel to a tangent at the limb, and usually about one millimeter within it. Precautions were always taken to prevent any light from the chromosphere from entering the slit. Hence, in all cases, the photographs of the spectrum of the limb represent the sun's disk, and not the region lying outside of it. After the exposure for the limb had been completed, a small sliding bar was moved over the slit, so as to cover the portion previously exposed, and light from the center of the sun was admitted on each side of the bar. Thus each photograph of the spectrum of the limb lies between two strips of spectrum representing the center of the sun. In the violet it is necessary to give from eight to ten times as much exposure at the limb as at the center. This ratio is reduced to four or five at the red end of the spectrum.

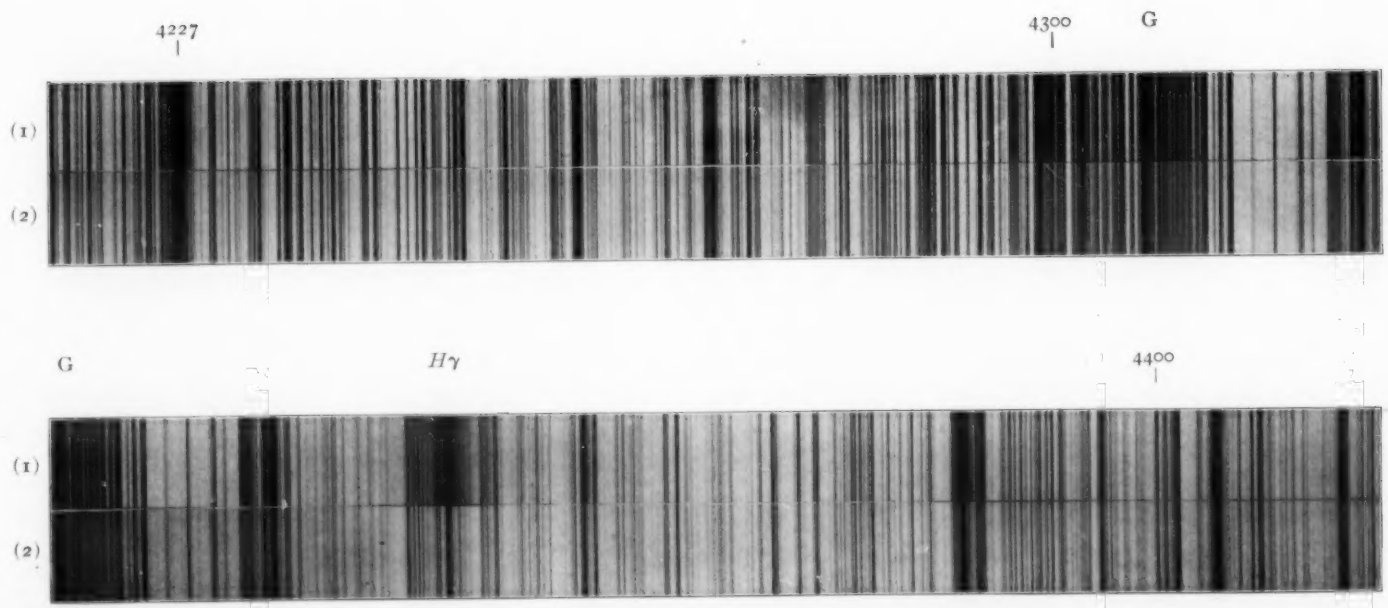
As an examination of Plates XVIII, XIX, and XX will indicate the differences in the relative intensities of the lines are not very marked in the less refrangible region, except in the case of such winged lines as D_1 and D_2, b_1, b_2, and b_4. In these cases the wings are greatly reduced in intensity, and the central portions of the lines are strengthened in the spectrum of the limb—a result which is in complete agreement with the observations of Hastings. There are some very distinct differences of line intensity to be noticed in this region, but such effects become far more marked in the blue and violet, and very conspicuous in the ultra-violet. In the region λ 3815–λ 3840 the appearance of the spectrum is greatly changed, through the almost complete disappearance of the wings which characterize the stronger lines corresponding to the center of the disk. So far as we have yet observed, in our preliminary examination of the plates, this practical elimination of the wings applies to all lines of this character. It is therefore to be regarded as the most striking feature of the spectrum of the sun's disk near the limb. In spots, on the other hand, a marked strengthening of the wings is a well-known characteristic in the less refrangible region of the spectrum. If this applies in the same degree to the much more closely crowded lines of the ultra-violet, it may be one of the causes contributing to the extreme weakness of the spot spectrum in this region.

PLATE XVIII



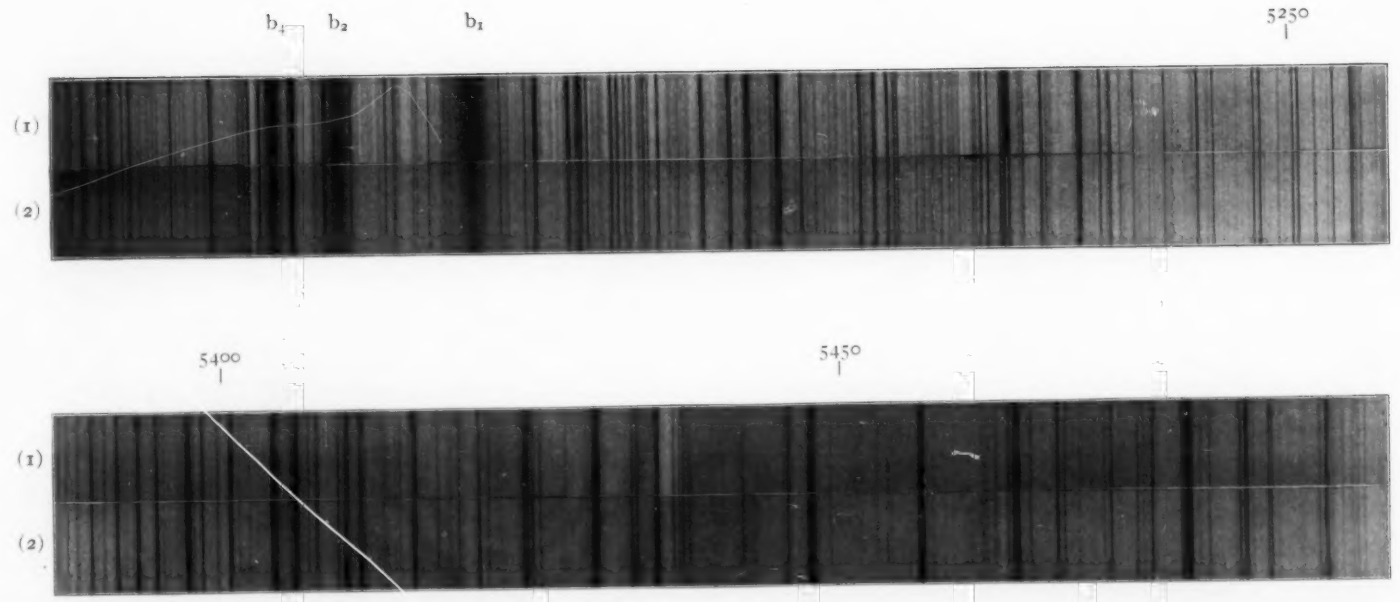
SPECTRA OF (1) CENTER OF SUN, (2) LIMB

PLATE XIX



SPECTRA OF (1) CENTER OF SUN, (2) LIMB

PLATE XX



SPECTRA OF (1) CENTER OF SUN, (2) LIMB

A second important distinction between the spectrum of the limb and the center lies in the changes in the relative intensities of the lines. In general, as the brief tables based upon a preliminary examination of several regions indicate, these changes of line intensity correspond closely with those observed in the case of sun-spots. In other words, lines that are strengthened in sun-spots are usually strengthened, in much smaller degree, near the sun's limb. Furthermore, lines which are weakened in sun-spots are usually weakened at the limb. Indeed, this latter effect seems to be relatively more marked than the effect of strengthening throughout the whole range of the spectrum. Some important exceptions have been noted, and others will no doubt appear in a more complete examination of the photographs. Nevertheless, the resemblance in this particular of the spectrum of the limb to that of sun-spots is very marked, especially in the less refrangible region. In the violet and ultra-violet the resemblance is partially concealed by the presence, in the case of spots, of an overlying solar spectrum. It is, however, clearly indicated. In our last paper we discussed the two principal sources to which this solar spectrum could be ascribed, namely, photospheric light and general sky illumination. Our present results on the spectrum of the center and the limb indicate that the photospheric light must probably be much the more important—a conclusion which agrees with that of Newall.[1]

In the tables which follow we give the results of our comparison of the spectrum of the center with that of the limb for three regions in different parts of the spectrum. The first of these includes a part of the G group and $H\gamma$; the second, the b lines and a portion of the green; and the third, a region in the yellow which is of considerable interest in sun-spot spectra. These results are merely preliminary and are given mainly to indicate the character of the evidence connecting changes in line intensities at the limb with those in spot spectra. In the abbreviations "Str." indicates that the line is strengthened, and "Str.+" that the effect is marked. Similarly "Wk." indicates that the line is weakened, and "Wk.+" that the amount of weakening is considerable. Lines in which the wings are reduced are indicated by "Sharp.," an abbreviation for sharpened.

[1] *Monthly Notices*, **67**, 158, January 1907.

TABLE I

Å	Element	Intensity Rowland	Spot	Limb
4299.15	*Ca*	3	Str.	Str.+
99.41	*Ti, Fe*	4		Sharp.
99.80	*Ti*	2	Str.	Wk.?
4300.21	*Ti*	3	Wk.?	N. C.
00.48	—	1 N		Wk.+
00.73	*Ti*	2	Str.	Wk.?
00.99	—	1	Wk.?	Wk.
01.16	*Ti*	2	N. C.	Wk.+
01.26	—	4		
01.33	—	1		
02.35	*Fe*	2		Wk.+
02.46	—	2		Wk.+
02.69	*Ca*	4	Str.+	Str.+
03.34	*Fe*	2	Wk.	Wk.+
03.75	—	1	N. C.	Wk.?
03.99	—	2	Wk.	Wk.+
04.10	—	4		
04.73	—	2	Wk.	Wk.+
05.27	—	1	Wk.?	Wk.+
05.48	*Fe, Sr*	1	Wk.	Wk.?
05.61	*Ti, Cr*	3		
05.87	—	2		N. C.
06.08	*Ti*	4	Str.	Wk.?
06.30	—	2	N. C.	Wk.+
06.86	—	–	Wk.	Wk.+
07.02	—	2		
07.46	—	2 N		Wk.+
07.72	—	2 Nd?		Wk.+
07.91	*Ca*	3	Str.	Str.+
08.08	*Fe, Ti*	6		Str.?
08.76	—	2 Nd?		Wk.++
09.06	—	1	Wk.	Wk.+
09.20	*Fe*	2		
09.54	*Fe*	3	Str.?	N. C.
09.79	—	1	Wk.	Wk.+
09.88	—	1		
10.27	—	2	Wk.	Wk.+
10.54	—	1	Wk.	Wk.+
10.63	—	2		
10.86	—	2	N. C.	Wk.+
11.06	—	1	Wk.	Wk.+
11.15	—	1		
11.32	—	2	N. C.	Wk.+
11.61	—	2	Wk.+	Wk.+
11.67	—	2		
12.25	—	2		Wk.+
12.46	—	2		Wk.
12.72	*Mn*	1 N		Wk.?
13.03	*Ti*	3	Wk.?	Wk.
13.19	—	1 N		Wk.
14.25	*Sc*	3	Str.	Str.+
15.14	*Ti*	3	Str.	N. C.
15.26	*Fe*	4		Str.
16.96	*Ti?*	1	Wk.?	N. C.

TABLE I—*Continued*

λ	Element	Intensity Rowland	Spot	Limb
4318.82	*Ca, Mn?*	4	Str.+	Str.+
20.91	*Sc*	3	Str.?	Str.?
21.12	*Ti?*	2	Wk.?	Str.?
21.96	*Fe*	2	Str.?	Wk.?
23.39	—	2	Wk.	Wk.+
23.67	—	1		Wk.+
23.77	—	0		Wk.+
24.01	—	3	Wk.	Wk.+
24.57	—	2	Wk.?	Wk.
25.15	*Sc*	4	Str.	N. C.
25.31	*Ti, Cr*	1		
25.52	*Ni, Zr*	1		Wk.+
25.94	*Fe*	8		Sharp.+
26.52	*Ti*	0	Str.+	Str.
26.92	*Fe*	2	Str.?	Str.?
28.08	*Fe*	2	Str.?	Wk.
30.19	*V*	0	Str.+	N. C.
30.40	—	1	Wk.	Wk.
30.87	*Ti, Ni*	2	Wk.	Wk.+
31.81	*Ni*	2	Str.	Str.+
32.99	*V*	0	Str.+	Str.?
33.92	*La*	1		Wk.+
35.10	*La*	0	Str.	N. C.
37.22	*Fe*	5	Str.	N. C.
37.72	*Cr*	3	Str.	Str.
38.08	*Ti*	4	Wk.	N. C.
38.43	*Fe*	1	Str.+	Str.
39.62	*Cr*	4	Str.+	Str.
39.88	*Cr*	3	Str.	Str.+
40.63	*H*	20	Wk.+	Wk.+Sharp.!
41.17	*V*	0	Str.+	Str.
41.53	*Ti?*	2	Wk.	N. C.
43.37	*Cr*	2	N. C.	N. C.
43.43	*Fe*	2		
44.67	*Cr*	4	Str.+	Str.+
46.99	*Cr*	1	Str.?	Wk.?
47.40	*Fe*	1	Str.+	Str.+
51.00	*Ti*	1	Wk.?	Wk.
51.22	*Cr*	3	Str.+	Str.+
51.93	*Cr, Fe*	5	Str.?	Wk.
52.08	*Mg*	5		N. C.
52.91	*Fe*	4	Str.+	Str.+
53.04	*V*	0		
55.26	*Ca?*	2	Str.	Wk.+
* * * *	* * * *	* * *	* * * *	* * * *
5137.25	*Ni*	3	Str.+	Str.+
39.43	*Fe*	4	Str.+	Str.
39.64	*Fe*	4	Str.?	Str.?
40.99	—	00	Wk.	Wk.
41.92	*Fe*	3	Str.+	Str.+
42.96	*Ni*	2	Wk.?	Wk.?
43.11	*Fe*	3	Str.	Str.
43.76	—	000	Str.+	Str.+
43.90	—	00		

TABLE I—*Continued*

Å	Element	Intensity Rowland	Spot	Limb
5144.85	*Cr, C*	oo	Str.+	Str.
45.27	*Fe*	1	Str.+	Str.+
45.64	*Ti*	o	Str.	Str.
46.66	*Ni*	3	N. C.	Str.? Wid.
47.65	*Ti*	o	Str.+	Str.+
48.22	*Fe*	2	Wk.	N. C.
48.41	*Fe*	3	Str.?	Wk.+
51.02	*Fe*	4	Str.+	Str.+
52.09	*Fe*	3	Str.+	Str.+
52.36	*Ti*	o	Str.+	Str.+
53.41	*Fe*	1		Wk.+
53.58	—	oo	Str.	
53.69	—	oo		
54.24	*Co*	2	Wk.	N. C.
55.94	*Ni*	2	Str.	Wk.
56.78	*C*	ooo	Str.	Str.?
56.82	*C*	oo		
59.23	*Fe*	2	Wk.	N. C.
62.45	*Fe, C*	5	Wk.?	Wk.+Sharp.
64.72	*Fe?*	1	Wk.	Wk.
65.59	*Fe*	2	N. C.	Str?
66.45	*Cr, Fe*	3	Str.	Str.+
67.50	*Mg*	15	Str.+	Str.+Sharp.!!
67.68	*Fe*	5		
69.07	*Fe*	3	Str.	Str.+
69.22	*Fe*	4	Wk.+	Wk.
70.94	*Fe*	o	Wk.+	Wk.+
71.78	*Fe*	6	Str.	Str.?
72.86	*Mg*	20	Str.+	Str.+Sharp.!!
73.92	*Ti*	2	Str.	Str.+
76.30	—	ooo	Str.	Str.
76.73	*Ni*	1	Wk.	Wk.
77.41	*Fe*	o	Str.?	Str.?
77.58	*Co*	oo		Str.?
80.23	*Fe*	1	Str.?	Str.?
83.79	*Mg*	30	Str.?	Str.+Sharp.!!
84.44	*Fe*	2	Wk.?	Wk.+
84.74	*Fe, Ni, Cr*	1	Wk.	Wk.+
86.07	*Ti*	2	Wk.+	Wk.?
88.08	*Fe*	1	Wk.	N. C. Wid.
88.86	*Ti*	2	Wk.	Wk.
89.02	*Ca*	3	Str.+	N. C.
91.63	*Fe*	4	Str.?	Str. Sharp.
92.52	*Fe*	5	Str.	Str. Sharp.
93.14	*Ti*	2	Str.+	Str.+
95.11	*Fe*	4	Str.+	Str.+
95.65	*Fe*	2	N. C.	Str.?
96.23	*Fe*	1	Str.	Str.
96.61	*Cr*	o	Str.	Str.
96.74	*Mn, Ni*	oo		Str.
97.33	*Mn*	oo	Wk.	N. C.
97.74	—	2	Wk.+	Wk.+
98.89	*Fe*	3	Str.+	Str.+
5200.59	*V*	o	Str.?	Str.

TABLE I—*Continued*

λ	Element	Intensity Rowland	Spot	Limb
5202.44	*Fe?*	2	N. C.	N. C.
02.52	*Fe*	4		
04.68	*Cr*	5	Str.+	Str.
04.76	*Fe*	3		
05.90	*Y*	0	Wk.?	Wk.?
06.22	*Cr–Ti*	5	Str.+	Str.+
08.11	*Ti*	00	Str.?	N. C.
08.60	*Cr*	5	Str.+	Str.+
08.78	*Fe*	2		Wk.?
10.56	*Ti*	3	Str.+	Str.+
11.70	*Fe*	00	Wk.	N. C.
16.44	*Fe*	3	Str.+	Str.+
17.55	*Fe*	3	Str.?	Str.
18.37	*Fe*	1	Wk.	Wk.
19.88	*Ti*	0	Str.+	Str.+
20.36	*Ni*	0	Wk.	N. C.
22.56	*Cr*	00	Str.	Str.
23.35	*Fe*	0	N. C.	Str.?
24.47	*Ti*	0	Str.	N. C.
25.10	*Cr*	0	Str.	Wk.
25.20	*Cr, Ti, Fe*	00		N. C.
25.70	*Fe*	2	Str.+	Str.+
26.71	*Ti*	2	Wk. Wid.	N. C. Wid.
27.04	*Fe–Cr*	3	Str.	Str.
27.36	*Fe*	5 d?	Str.+	Str. Sharp.
30.03	*Fe*	4	Wk.?	N. C.
30.38	*Co, Cr*	00	Str.	Str.?
33.12	*Fe*	7	Str.+	Str. Sharp.!
34.79	—	2	Wk.+	Wk.+
35.56	*Fe*	1	Wk.	Wk.
35.67	*Ni*	00		
36.37	—	0	Wk.	Wk.
37.49	*Cr?*	1	Wk.	Wk.
38.74	*Ti*	000	Str.+	Str.+
39.14	*Cr*	00	Str.	Str.
39.99	—	1	Wk.?	N. C.
42.66	*Fe*	2	Str.?	N. C.
43.95	*Fe*	1	N. C.	N. C.
47.23	*Fe*	1	Str.+	Str.+
47.74	*Cr*	2	Str.+	Str.+
* * * *	* * * *	* * *	* * * *	* * * *
5397.34	*Fe*	7 d?	Str.+	Str. Sharp.
98.49	*Fe*	3	Wk.?	N. C.
99.68	*Mn*	1 Nd?	Str.?	N. C.
5400.71	*Fe*	3	Wk.?	Wk.+
00.83	*Cr*	00		
04.03	*Fe*	2	Wk.?	N. C.
04.36	*Fe*	5	N. C.	Wk.? Sharp.
05.99	*Fe*	6	Str.+	Str. Sharp.
07.59	*Mn*	0	Str.	Str.
07.69		0		
07.82	—	00	Wk.+	Wk.
09.34	*Fe*	2	Wk.+	Wk.
10.00	*Cr*	4	Str.+	Str.+

TABLE I—*Continued*

λ	Element	Intensity Rowland	Spot	Limb
5411.12	*Fe*	4	Wk.?	Wk.
11.43	*Ni*	1	Wk.+	Wk.
14.28	—	oo	Wk.	Wk.
15.42	*Fe–V*	5	N. C.	N. C. Sharp.
18.98	*Ti?*	1	Wk.?	N. C. Wid.
20.55 } 20.61 }	*Mn*	o } o }	Str.+	Str.+
24.29	*Fe*	6	N. C.	N. C. Sharp.
24.86	*Ni*	1	Str.?	Str.
25.46	—	1	Wk.	Wk.
26.47	—	oo	Str.+	Str.
29.72	—	1	Wk.?	Wk.+
29.91	*Fe*	6 d?	Str.+	Str.+Sharp.
32.75	*Mn*	1 Nd?	Str.+	Str.+
34.74	*Fe*	5	Str.+	Str.+Sharp.
36.07	*Ni*	2	Str.?	Str.
36.51	*Fe*	1	Wk.?	N. C.
36.80	*Fe*	1	Str.+	Str.
41.55	*Fe?*	1	Wk.?	N. C.
45.26	*Fe*	4	Wk.?	N. C.
46.80	*Ti*	2	Str.+	Wk.?
47.13	*Fe*	6 d?	Str.+	Str. Sharp.
55.67	*Fe?*	2 }	Str.	} Wk.
55.83	*Fe*	4 }		} Str.
60.72	—	oo	Str.+	Str.
61.76	—	o	Str.	N. C.
63.17	*Fe*	3	Wk.?	Wk.?
66.61	*Fe*	3	Str.	Str.?
67.20	*Fe*	1	Str.?	Str.?
70.80 } 70.88 }	*Mn*	o } o }	Str.+	Str.
72.92	*Fe*	1	Str.	Str.
74.11	*Fe*	3	Wk.	Wk.
76.50	*Fe*	1	Wk.?	Wk.+
77.12	*Ni*	5	Str.+	Str.? Wid.
77.90	*Ti*	oo	Str.+	N. C.
78.67	*Fe*	o	Wk.	Wk.
81.45	*Fe*	1	N. C.	Wk.
81.65	*Fe, Ti*	1	Str.	Wk.?
82.08	—	oo	Str.+	Str.
83.31	*Fe*	1	Wk.	Wk.
83.57	*Co*	1 d?	Str.+	Str.+
90.37	*Ti*	o	Str.+	Str.+
93.71	*Fe*	1	Str.	Str.?
97.74	*Fe*	5	Str.+	Str. Sharp.

The tendency toward a weakening of the spark lines, which is unmistakable though not very marked in the less refrangible region of the spectrum, becomes conspicuous in the violet and ultra-violet. The following list, taken from Lockyer's "Tables of the Wave-Length of Enhanced Lines," indicates the behavior in this respect of the more prominent spark lines of *Fe*, *Ti*, and *V* in the ultra-violet region. Identifications not made by Rowland are entered in brackets.

TABLE II

λ	Element	Intensity Rowland	Spot	Limb
3685.34	*Ti*	10 d?	Wk.	Wk.++
3706.36	*Ti*	3		Wk.+
3721.78	*Ti*	4 d?	Wk.	Wk.++
3741.79	*Ti*	4	Wk.	Wk.++
3748.14	*Ti*	1		Wk.++
3757.82	*Cr–Ti*	4	Wk.?	Wk.++
3759.45	*Ti*	12 d?	Wk.+	Wk.++Sharp.!
3761.46	*Ti*	7	Wk.+	Wk.++
3762.01	*Ti*	3		Wk.+
3776.20	*Ti*	2		Wk.+
3813.54	*C (Ti)*	2		Wk.+
3814.74	*–C (Ti)*	3		Wk.+
3836.23	*(Ti)*	2		Wk.
3839.76	*Fe*	2	Wk.	Wk.++
3846.55	*Fe*	2		Wk.++
3863.89	*Fe*	3	Wk.	Wk.++Sharp.
3866.96	*C–(V)*	2	Wk.?	Wk.+
3878.88	*C–Fe (V)*	2	Wk.?	Wk.++
3900.68	*Ti–Fe–Cr*	5		Wk.++
3903.40	*(V)*	2	Wk.	Wk.++
3913.61	*Ti–Fe*	5 d?	Wk.	Wk.
3914.43	*Fe? (V)*	3		Wk.++
3916.54	*(V)*	3	Wk.?	Wk.+
3935.96	*Fe*	2		Wk.
3939.29	*(Fe)*	0		Wk.+
3987.76	*Ti?*	2	Wk.?	N. C.
4005.86	*(V)*	3		Wk.+
4012.54	*Ti*	4		Wk.

In considering the behavior of the lines of different elements, we encounter at once an interesting peculiarity, which may prove significant. In the spot spectrum the lines of titanium and vanadium are well known to be very conspicuous, because, in most cases, they are strengthened more than the lines of other substances. In the spectrum of the limb, however, while these lines seem to be affected in the same direction as in spots, the magnitude of the effect is decidedly less than in the case of manganese, iron, calcium, and other substances, which appear to behave more nearly as they do in spots.

Hydrogen offers another case of great interest, with one apparent anomaly. $H\beta$ is not satisfactorily shown on the photographs at present available, and may for the present be left out of consideration. $H\gamma$ and $H\delta$ are much sharper and narrower at the limb than at the center of the sun, largely through the weakening of the wings which accompany these lines. The central part of the lines also appears to be slightly weakened at the limb. In spots they act in the same way, but the effect is more marked. $H\alpha$ is certainly widened at the

limb and possibly somewhat strengthened. There appears to be no great change in the sharpness of the line, the edges being slightly diffuse in both cases. In spots, on the contrary, *Hα* is much narrower than in the spectrum of the sun's center and is also weakened. We have as yet found no means of explaining this apparent anomaly.

Carbon and cyanogen are particularly interesting. Many lines in the violet carbon band are of unchanged intensity, or perhaps slightly strengthened, at the limb. The cyanogen fluting, which begins at λ 3884, is, on the contrary, very decidedly weakened at the limb. This is clearly shown in Plate XVIII.

The behavior of the spark lines is a matter of special interest. In addition to the lines given in the list, the very noticeable weakening of most of the lines of the G group may be mentioned. The great majority of these are unidentified by Rowland, and are probably spark lines. The more conspicuous of these lines are weakened in spots, and doubtless others would be were they not concealed, as suggested in our last paper,[1] by the overlying solar spectrum.

The behavior of the line λ 4233.3, which is probably mainly due to enhanced *Fe*, as shown by Lockyer, is of special interest, as this line is very strong in the flash spectrum. At the limb, on the contrary, it is much weakened. There are doubtless many other cases of this kind which will require careful investigation.

The bearing of these results on solar theory cannot properly be discussed until much more material is available, particularly as regards relative intensities and line shifts. These investigations are now in progress, and we therefore reserve further discussion for a later paper, in spite of various seemingly obvious consequences which at once suggest themselves. For example, it now seems difficult to reconcile our results as to the disappearance of wings at the limb with Halm's conclusion that the dense vapors lying close to the photosphere contribute relatively more at the limb than at the center to the formation of the absorption lines. We hope at an early date to be able to discuss this point fully, as well as many more of equal interest.

APRIL, 1907

[1] *Contributions from the Solar Observatory*, No. 15; *Astrophysical Journal*, **25**, 75 1907.

SOME NEW APPLICATIONS OF THE SPECTRO-HELIOGRAPH[1]

By GEORGE E. HALE

I. SOLAR PHOTOGRAPHY WITH SUN-SPOT LINES

In several previous papers I have remarked on the importance of photographing the sun with the lines affected in and near spots. In our photographs of spot spectra many lines are strengthened or weakened, not merely in the umbra and penumbra, but in extensive regions surrounding spots. This effect, conspicuous enough to show itself directly in the spectrum, is evidently within easy reach of the spectroheliograph. Furthermore, our experience in the photography of faint hydrogen flocculi warrants the inference that spot phenomena, too delicate in their effect on line intensity to be detected with the spectrograph, will be brought to light by the application of spectroheliographs of sufficiently high dispersion.

The question of dispersion is evidently of crucial importance. If the line employed is sensibly narrower than the camera slit of the spectroheliograph, the admixture of light from the adjoining continuous spectrum will tend to blot out the comparatively feeble impression resulting from the faint light of the dark line. The fact that many of the most interesting cases are represented by extremely fine lines thus points to the use of spectroheliographs of great linear dispersion. This consideration, and the desire to photograph the sun with narrow dark lines other than those affected in spots, led to the provision of four prisms for the 5-foot spectroheliograph[2] and the inclusion, in the original plan of the Snow telescope house, of a spectroheliograph of 30 feet (9.14 m) focal length.[3] The latter instrument has not yet been completed. The delay is due in part to difficulty in securing suitable prisms, and in part to the distortion of the Snow telescope mirrors in sunlight. This distortion, while inappreciable

[1] *Contributions from the Solar Observatory of the Carnegie Institution of Washington*, No. 18.

[2] *Contributions from the Solar Observatory*, No. 7, p. 6; *Astrophysical Journal*, **23**, 59, 1906. This instrument has been used systematically since October, 1905 for photographic work with some of the wider dark lines.

[3] *Contributions*, No. 2 p. 14; *Astrophysical Journal*, **21**, 64, 1905.

during the short exposures that suffice with the 5-foot spectroheliograph, would change the focus and seriously affect the definition of the solar image during the long exposures required with much higher dispersion. As explained in a previous paper,[1] it is hoped that such distortion may be overcome in our new vertical telescope, to which the 30-foot spectroheliograph will be transferred.

Meanwhile, a temporary spectroheliograph of 30 feet focal length has been successfully used with the Snow telescope. This instrument was mounted in the telescope house, between the second mirror of the coelostat and the concave mirror of 60 feet focal length. Instead of the latter, a 5-inch (12.7 cm) objective, of 13 feet (3.96 m) focal length, was used to form the solar image on the collimator slit. The spectroheliograph was built in the Littrow form, with camera slit immediately below the collimator slit; an 8-inch (20.3 cm) objective, of 30 feet focal length, serving at once as collimator and camera lens, and a 6-inch plane grating. As the entire spectroheliograph was supported in a fixed position on piers, it was necessary to cause the solar image to move across the collimator slit, and the photographic plate across the camera slit, at a slow and uniform speed. This was accomplished by mounting the 5-inch image-forming objective and the plate holder (13 feet apart) on arms supported at opposite ends of the movable carriage of the 5-foot spectroheliograph. The driving mechanism of this instrument,[2] supplemented by a counter-shaft for slower speeds, served admirably to give the necessary motion.

On account of the small aperture (only a part of which was used) and the short focal length of the image-forming objective, no appreciable change of focus occurred during the exposures. The small diameter of the solar image (1.4 inches = 3.5 cm) prevented the minor details of structure from being recorded, but enough was shown to serve as a good test of the apparatus and its possibilities.

Several photographs of each spot were made by Mr. Adams and myself on each plate, the first exposure with the camera slit set on the dark line, the other exposures with this slit set on the continuous spectrum, a short distance from the line. In order to eliminate the

[1] *Contributions from the Solar Observatory*, No. 14; *Astrophysical Journal*, **25**, 68, 1907.

[2] *Contributions*, No. 7, p. 7; *Astrophysical Journal*, **23**, 60, 1906.

effect of increased brightness of background, due to the absence of the dark line from the slit in the continuous spectrum photographs, these were repeated, with different speeds of driving.

The first lines tried were those that are strengthened in the umbra and penumbra and on the photosphere, for a considerable distance from spots. The spectroheliograph plates made with such spot lines show the umbra and penumbra much darker than they appear on the plates taken with the light of the continuous spectrum. The apparent diameter of the spot also appears to be considerably increased, doubtless through the inclusion of the dark area surrounding it.

Lines that are weakened in spots, and on the adjoining photosphere, also give definite effects, though the results so far obtained are less satisfactory than in the case of the strengthened lines.

With a large solar image and good conditions of atmosphere, such a spectroheliograph as the one described above is capable of yielding many interesting results, if used systematically with lines affected in spots and with other dark lines. The 30-foot spectroheliograph designed for the "tower telescope" should, however, be much more efficient in many respects than this temporary instrument. The dark areas frequently observed on the sun with the aid of D_3, usually in the vicinity of sun-spots, indicate that spectroheliographic records, made with the light of this line, will also prove of great value. In fact, the promise of future work with this and numerous other lines is so great that the efforts of many investigators, provided with the most powerful instruments, will be required to derive adequate results in this extensive field.

II. STEREOSCOPIC PICTURES OF THE SUN

The application of stereoscopic methods to solar work dates back to the time of De La Rue, who secured interesting results through the combination in the stereoscope of direct photographs of the sun taken at various time intervals, up to two days. These pictures, according to his descriptions, showed the spots as depressions and the faculae as elevated regions. Since his time but little appears to have been done in this field.

In the summer of 1906 I thought it would be of interest to combine, with the aid of our large stereocomparator, various plates made with

the Snow telescope and 5-foot spectroheliograph. The results were very satisfactory, showing at once the sphericity of the sun and, to most observers, the protuberant character and cloudlike aspect of the flocculi. If the interval is too short, the effect is imperceptible; if too long, the changes in form of the flocculi, and the large displacements due to the solar rotation, trouble the eye when attempting to unite the images.

The photographs reproduced in Plate XXI were taken on August 22, 1906, at $7^h\ 26^m$ A. M. and $5^h\ 21^m$ P. M. During this interval the changes in the form of the flocculi are very noticeable, but do not prevent a fairly satisfactory combination of the images when a glass positive is viewed with a stereoscope. It is doubtful whether the half-tone print will give satisfactory results, though the sphericity of the sun should be evident.

As for the appearance of the flocculi as elevated regions, this is much better shown with the aid of the original negatives, or with positives reproduced on the same scale. The stereocomparator, provided with all facilities for centering and adjusting plates, permits the observations to be made in a most satisfactory manner. It should be stated, however, that some observers see the flocculi as apparent depressions rather than as elevations. This, however, is uncommon.

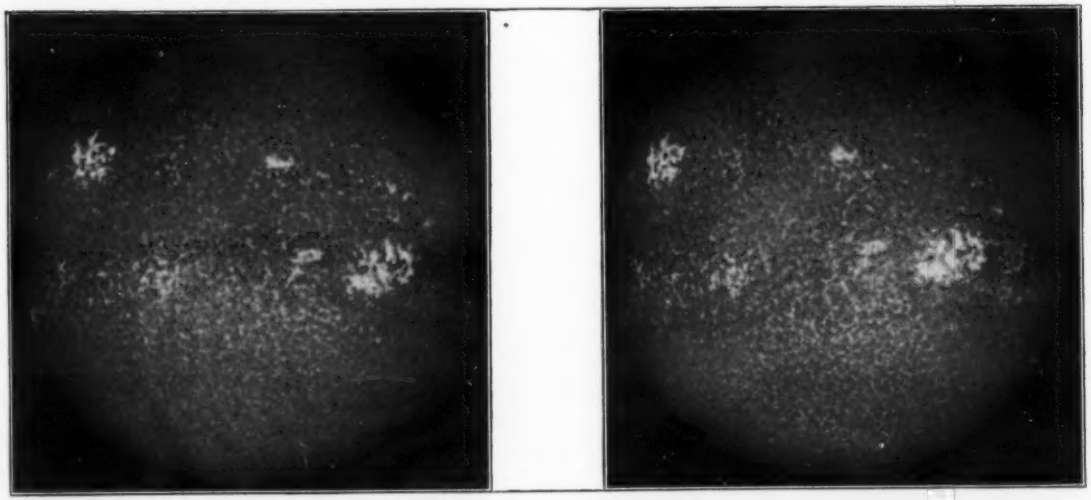
It seems probable that further studies of this character will bring useful results. It has already been possible to detect in this way linear markings on the solar surface, of great extent, which do not readily strike the eye when plates are examined singly. For purposes of measurement, and the detection of minute differences of form, the monocular eyepiece, with micrometer attachment, which is furnished by Zeiss as an accessory of the stereocomparator, is of course to be employed. It nevertheless appears probable that the stereoscopic method will prove to have certain advantages of its own, which will recommend it to those who are engaged in the study of spectroheliograph plates.

April, 1907

PLATE XXI

THE SUN, AUGUST 22, 1906

$5^h\ 21^m$ P. M. $7^h\ 26^m$ A. M.



ORBIT OF THE SPECTROSCOPIC BINARY κ *CANCRI*

By NAOZO ICHINOHE

This star ($\alpha = 9^h\ 2^m$, $\delta = +11°\ 4'$; Mag. *H. P.*, 5.0; *D. C.*, 5.3; *P. D.*, 5.5) was found as a spectroscopic binary at Yerkes Observatory by Messrs. Frost and Adams, in the course of the regular programme of work on stars having spectra of the *Orion* type. Their measures of the first five plates taken (IB 256, 267, 286, 289, 305) will be found in their paper.[1] At the suggestion of Mr. Frost, I began last summer to measure the spectrograms of the star taken later than the above plates.

The spectrum of this star belongs to the later stage of development from the *Orion* type toward the Sirian type. The hydrogen lines are strong and well defined. The helium lines λλ 4009, 4026, 4144, 4388, and 4472 are scarcely visible. The carbon line λ 4267 is well seen; the silicon lines λλ 4128 and 4131 are very good for measurement, as they are quite strong and well defined. The K line is sharp and strong, and the magnesium line λ 4481 is also well defined. Besides these, many faint lines of *Fe* and *Ti*, especially *Fe* λ 4550, can be seen. But generally, on a slightly over-exposed plate, the metallic lines become very faint and difficult to measure; while the hydrogen lines have very good definition on such plates. For under-exposed plates, on the contrary, the hydrogen lines are broad and diffuse, while the *Mg* line, as well as other metallic lines, are more distinct. The only lines in this spectral region which are always distinct are *Si* λ 4128 and λ 4131.

I measured almost all the lines visible on the plates, but of course many of them are too faint to give precise values of the radial velocity, so that only the following lines were chosen for the determination of velocities:

K	3933.825	*Ti*	4344.451
Hδ	4101.890	*Mg*	4481.400
Si	4128.211	*Fe*	4549.808
Si	4131.047	*Ti*	4572.156
Fe	4233.328	*Fe*	4584.018
C	4267.301	*Ti*	4590.126
Ti	4338.084	*Ti*	4856.203
Hγ	4340.634	*Hβ*	4861.527

[1] *Astrophysical Journal*, **19**, 351, 1904.

The number of spectrograms of κ *Cancri* obtained here up to date is twenty-five, the particulars as to which follow. For all of these plates the spectrograph was used with one prism. For the collimator $\frac{a}{f}=\frac{51\text{ mm}}{958\text{ mm}}$; for the camera $\frac{a}{f}=\frac{57}{608}$. The scale-values at different wave-lengths are approximately as follows:

λ	$\frac{d\lambda}{ds}$	
3933.....	1 mm=16.5 t.-m.=	1264 km per sec.
4045.....	18.9	1404
4338.....	25.9	1788
4481.....	29.6	1984
4552.....	31.6	2083
4856.....	40.9	2523

The spark spectrum of titanium and iron was impressed on each plate at the beginning and end of the exposure. The slit-width was varied to suit the conditions of the atmosphere. The third column of the following table gives the G. M. T. of mid-exposure. The temperature (C.) is that within the outer case of the spectrograph. Under observer, A = Adams, B = Barrett, F = Frost. The seeing is estimated by the observer on a scale of 1–5, 5 representing the finest conditions.

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Plate	Date	G. M. T.	Exposure	Slit-Width	Temperature	Observer	Seeing
IB 256	1904 Jan. 21	22^h44^m	63^m	0.038mm	−13°.8 C.	A	3
267	Jan. 23	20 44	50	.051	−12.4	A	3–2
286	Feb. 26	18 38	50	.044	− 7.8	A	2–1
289	March 8	18 36	48	.038	+ 2.2	F	3
305	April 15	15 25	50	.038	+ 0.1	A	3–2
330	April 30	15 50	56	.038	+16.2	F	3–2
471	Dec. 30	20.18	67	.041	+ 2.2	B	3–1
482	1905 Jan. 9	21 00	76	.041	−13.0	F	2–1
500	Feb. 3	18 39	50	.051	−16.6	F–B	2–3
626	Dec. 9	20 11	46	.051	− 0.5	F	3–2
633	Dec. 11	21 06	48	.051	+ 4.2	B	3–2
644	Dec. 15	22 21	50	.054	+ 0.2	F	3
653	Dec. 25	20 07	66	.051	− 2.9	B	3–1
662	1906 Jan. 26	18 54	52	.059	+ 3.2	B	3–2
713	March 23	15 59	92	.051	− 4.6	F	2–0
732	April 20	14 03	60	.059	+18.7	B	3–2
740	April 23	14 14	52	.051	+ 9.7	F	3
746	April 27	14 15	60	.051	+15.5	B	3–2
899	Oct. 31	23 34	37	.051	+ 5.2	B	3–2
949	1907 Jan. 21	21 18	120	.051	−10.2	F	1–2
999	Feb. 22	19 26	55	.051	− 8.9	B	3
1018	April 13	17 13	50	.046	− 0.6	Fox	4–2
1027	April 20	15 40	63	.046	+ 6.1	Fox	3–2
1039	April 26	14 57	74	.051	+ 3.6	F	3–2
1052	May 10	14 26	71	.051	+ 6.0	B	2

Plate No. 644 is very weak and unsuited for accurate measurement, so that it is omitted from the discussion. All of the other plates, except the five by Frost and Adams, were measured by me. The method of measurement and reduction is that regularly employed at this observatory. The number of lines on each plate used for the determination of radial velocity is not constant, varying from nine to three according to the nature of the plates, but generally five or six lines were chosen. The weight for each line is assigned during measurement, depending upon the character of line on the plate, and the weighted mean is taken for the radial velocity. The following table contains all the data for the determination of the orbit of *κ Cancri*. The first column gives the number of the plate; the second, the date expressed in Julian days; the third, the radial velocity reduced to the sun; the fourth, the number of lines used for the determination of v.

Plate No.	Julian Day	v	n	Phase	v_c	$v-v_c$
		km			km	km
256	2416482.947	+ 2.5	7	1.000	+ 9.2	−6.7
267	6503.864	+88.3	5	2.738	+81.8	+6.5
286	6537.776	+34.9	5	4.685	+31.2	+3.7
289	6548.775	+82.7	9	2.898	+83.5	−0.8
305	6586.643	+70.0	5	2.408	+75.3	−5.3
330	6601.660	+31.2	8	4.639	+34.3	−3.1
471	6845.846	−44.5	4	5.891	−47.3	+2.8
482	6855.875	+85.6	6	3.134	+84.4	+1.2
500	6880.777	+73.7	9	2.464	+76.7	−3.0
626	7189.841	+38.8	7	4.664	+32.6	+6.2
633	7191.879	−36.1	5	6.702	−34.1	−2.0
653	7205.838	+37.9	4	1.482	+38.1	−0.2
662	7237.788	+33.7	7	1.467	+37.3	−3.6
713	7293.666	−52.9	3	6.201	−50.7	−2.2
732	7321.585	+61.5	5	2.155	+67.9	−6.4
740	7324.593	− 3.6	5	5.163	− 5.1	+1.5
746	7328.594	+89.1	3	2.771	+82.3	+6.8
899	7515.982	+20.0	6	4.762	+25.7	−5.7
949	7597.888	+85.9	6	3.559	+80.8	+5.1
999	7629.810	+78.2	6	3.516	+81.8	−3.6
1018	7679.718	+71.8	5	2.280	+71.8	0.0
1027	7686.653	+76.2	4	2.822	+82.8	−6.6
1039	7692.621	+70.2	7	2.397	+75.1	−4.9
1052	7706.601	+82.2	3	3.591	+80.4	+1.8

The period was investigated last summer, and after several trials it is found to be $3^d.393$. Although many plates were taken after this period was obtained, all of them gave values pretty close to the

expected velocity. Accordingly, I believe that the above value of the period is accurate within one one-thousandth of a day.

Taking $3^d.393$ for the period, the phases were now calculated, as shown in the fifth column of the above table. For this the date of the first plate was assumed as phase $1^d.000$. Then the values of v were taken as the ordinates, and the phases as the abscissas of a system of rectangular co-ordinates. The points defined by these co-ordinates were plotted on millimeter paper, on a scale of 1 day = 50 mm, 1 km = 2 mm, and a smooth curve was drawn passing through these points as well as possible, and such that the curve will fulfil the conditions for the determination of the orbit by the method of Lehmann-Filhés.

The radial velocity of the center of gravity of the system is first found by shifting the axis of abscissas until the area inclosed by the curve above the axis becomes equal to that below the axis. We thus obtain

$$\text{Radial velocity of the system} = +26.3 \text{ km}.$$

Then the maximum A and minimum B of the radial velocity, z_1, z_2 and t_1, t_2 were determined as follows:

$$\begin{array}{ll} A = 58.2 \text{ km}, & B = 77.4 \text{ km} \\ z_1 = 6160 \text{ sq. mm}, & z_2 = -6750 \text{ sq. mm} \\ t_1 = 4^d.760, & t_2 = 7^d.725. \end{array}$$

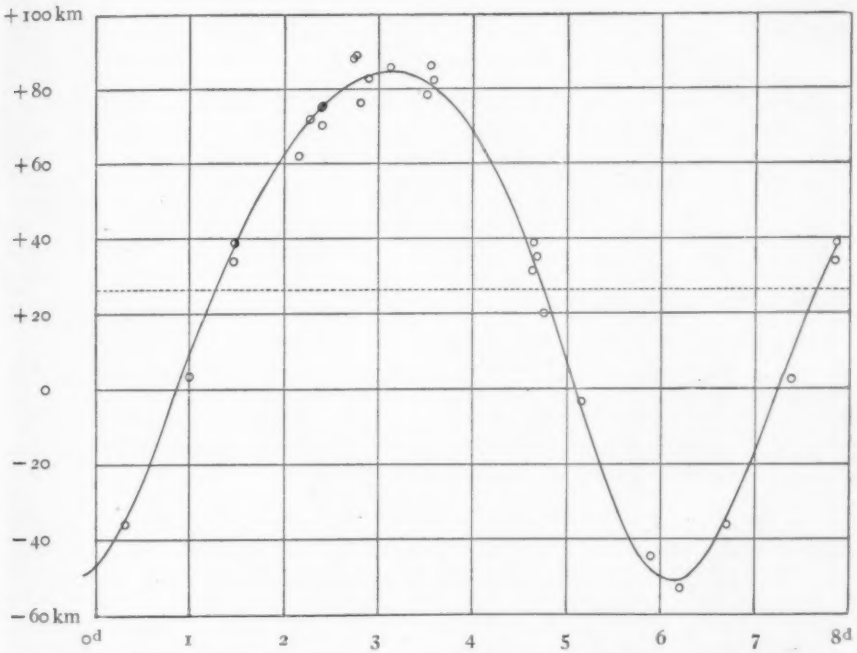
The following elements were derived:

$$\begin{array}{c} U = 6^d.393 \\ u_1 = 81^\circ\ 51'.2 \\ \omega = 162^\circ\ 15'.8 \\ e = 0.149 \\ \mu = 56^\circ.31 \\ \text{or } \log \mu = 1.75060 \\ T = 1904 \text{ Jan. } 6.897 \\ a \sin i = 5{,}890{,}000 \text{ km} \end{array}$$

In order to see if the elements satisfactorily represent the observations, an ephemeris was calculated; the computed values will be found in the sixth column of the above table. The last column of the same table gives the residuals, observation minus computation. The residuals are pretty large, ranging from +7 km to −7 km, but they may be regarded as fairly satisfactory, since all these plates

were taken with one prism. The mean error of a single plate is ±4.2 km. There is no appreciable evidence of systematic errors in the residuals.

I did not try to correct the elements further, as the observational data are not yet adequate for the calculation of the definitive orbit. The accompanying figure shows the computed curve and observed points.



COMPUTED VELOCITY-CURVE FOR κ *Cancri*, WITH OBSERVED POINTS

The above relates exclusively to the principal component of the spectrum of *κ Cancri;* but the star shows another spectrum, as was pointed out by Frost and Adams. I was able to see the faint component of the spectrum on eighteen plates out of twenty-five. These lines are so extremely faint that it is very difficult to measure them, and the results are liable to great errors. The discussion of the orbit of the fainter component is therefore deferred until additional plates can be obtained and greater certainty assured.

YERKES OBSERVATORY
May, 1907

ORBIT OF THE SPECTROSCOPIC BINARY β *ARIETIS*[1]

By H. LUDENDORFF

The variability of the radial velocity of β *Arietis* was announced in 1903 by Director Vogel[2] as a result of his measurements of 14 spectrograms obtained by Messrs. Eberhard and Scholz and myself with spectrograph IV (three prisms) attached to the 32.5-cm photographic refractor of the Potsdam Observatory during the period from 1902 to the beginning of February 1903. At the request of Professor Vogel, I subsequently investigated the radial velocity of this star more minutely, measuring again the fourteen plates mentioned and twenty-three additional ones obtained up to the end of 1904. The results of this investigation were published in *Astronomische Nachrichten*, No. 4090 (**171**, 149, 1906). As no determinations of the radial velocity by other observatories were available, I had to depend solely on the thirty-seven plates obtained here. I was only able to conclude that the period was $32/n$, where n is an integer $\leqq 5$. It further appeared that the radial velocity was almost constant during a considerable fraction of the period.

Thirty-nine more spectrograms of β *Arietis* were obtained by Dr. Eberhard and myself with spectrograph IV in the winter season of 1906–7, and these in connection with the thirty-seven earlier plates now permit a first determination of the orbit.

The spectrum of β *Arietis* is to be assigned to Vogel's class Ia2. The lines are all broad and diffuse; and in the region sharply defined by spectrograph IV (λ 4300 to λ 4530) only two absorption lines, *Mg* λ 4481 and $H\gamma$, could be measured. No indication of the second component of the star could be recognized in the spectrum. The magnesium line does indeed appear double on plates Nos. 1354 and 1355, as stated by Vogel in his paper referred to, but I have been unable to detect this appearance with certainty in any of the other

[1] Translated from advance proofs, sent by the author, of a paper to appear in the *Sitzungsberichte der Berliner Akademie*.

[2] *Astronomische Nachrichten*, **163**, 145, 1903.

seventy-four plates. It is therefore to be assumed that the duplicity of the *Mg* line on these two plates may be explained by special disturbances in the atmosphere of the star. Similar phenomena have often been observed here in the case of stars of the first type.

On account of the width and diffuseness of the *Mg* and *Hγ* lines, the measurements of the radial velocity of *β Arietis* are quite uncertain. In order to overcome as much as possible the effect of a subjective error in setting, I employed a reversion-prism in the measurements, so that the position of the spectrum could be apparently reversed through 180° after the completion of the series of measurements in the first direction; the mean of the two series was then employed.

Since the measurements of the *Hγ* line were decidedly more uncertain than those of the *Mg* line, they were assigned only half-weight in the reduction. It was not possible to measure *Hγ* at all on several of the underexposed plates (Nos. 1187, 1361, 1390, 1529, 1745, 1752, 2054, 2057, 2058, 2063, 2066). On those plates the *Mg* line was measured twice, and the mean taken from the two wholly independent series of measures. Those plates were also twice measured which gave values of the radial velocity differing from each other by more than 15 km; the plates were Nos. 1329, 1343, 1355, 1513, 1748, 1759, 2008, 2025, 2036, and 2060.

The uncertainty of the radial velocity from the measurements of a single plate may amount to 10 km, in some cases even more. The results from the sixty-five plates on which both the *Mg* line and *Hγ* were measured indicate in the mean that a receding velocity of the star greater by 3 km may be inferred from the *Mg* line than from *Hγ*.

The following summary shows all the data which I employed for the determination of the orbit. It gives the number of the plates, the date, Central European Time of mid-exposure, the observers at the telescope (E = Eberhard, L = Ludendorff, S = Scholz), the radial velocity reduced to the sun, and finally, in the last column, the phase Φ computed after the period had been determined, i. e., the interval expressed in days from the next preceding maximum of the radial velocity.

No.	Date		C. E. T.	Observer	v	Φ
1187	1902 Oct.	21	$9^h\ 48^m$	E, S	− 8km	$+17^d$
1196		22	10 24	E, S	− 2	18
1323	1903 Jan.	17	6 55	E, S	+31	105
1329		18	6 23	E	+43	106
1334		19	6 27	E, L	+60	0
1337		20	6 10	E, L	+19	1
1340		21	6 11	E, L	+12	2
1343		22	5 37	E, L	0	3
1349		27	7 2	E	+ 2	8
1350		28	7 41	E, L	−11	9
1354		29	5 44	L	−10	10
1355		31	9 42	E	− 1	12
1356	Feb.	2	6 0	E, S	− 8	14
1361		6	6 4	E, S	0	18
1363		6	8 28	E, S	− 5	18
1368		15	6 24	E	− 5	27
1374		16	6 13	E, L	+ 6	28
1381		19	6 30	E, L	− 4	31
1383		20	6 23	E, L	− 8	32
1386		24	6 30	E, L	− 7	36
1389	March	2	6 57	E, S	0	42
1390		4	6 59	E, S	− 5	44
1391		7	6 58	E, S	− 6	47
1394		8	7 4	E	− 8	48
1513	Dec.	3	8 6	E, L	+24	104
1521		4	8 47	E, L	+36	105
1526		22	8 24	E, L	− 2	16
1529		25	6 8	E	−17	19
1533		28	7 34	E, L	− 8	22
1537	1904 Jan.	4	6 7	E	− 4	29
1549		11	6 11	L	− 9	36
1584	Feb.	12	6 10	L	+ 4	68
1745	Dec.	6	6 53	L	− 8	45
1748		9	8 5	E, L	+ 5	48
1752		12	6 47	E	−10	51
1755		13	6 32	L	− 7	52
1759		16	6 50	L	− 5	55
1994	1906 Sept.	27	10 15	E	+10	63
1995		28	9 31	L	− 9	64
1997		30	9 45	E	0	66
1999	Oct.	1	9 33	L	− 6	67
2003		8	9 32	E, L	− 7	74
2005		9	10 27	E, L	−11	75
2006		10	10 24	E	+ 1	76
2008		13	9 21	E, L	+ 8	79
2009		17	8 27	E, L	+ 2	83
2014	Nov.	6	9 47	E	+21	103
2016		8	7 50	L	+34	105
2017		8	9 0	L	+27	105
2020		9	6 21	L	+39	106
2022		9	8 55	E, L	+41	106
2025		10	7 8	L	+57	0
2026		10	8 22	E	+57	0
2027		14	8 17	E	+ 1	4
2028		15	6 33	L	− 8	5
2032		20	8 56	E, L	− 5	10

No.	Date		C. E. T.	Observer	v	Φ
2036	Nov.	24	$7^h\ 13^m$	E	− 2km	14
2040	Dec.	1	9 3	L	− 7	21
2043		7	6 8	E	− 8	27
2048		8	9 9	E, L	−18	28
2050		22	6 17	L	− 2	42
2054		27	7 5	E	+ 4	47
2057	1907 Feb.	11	6 41	E	− 7	93
2058		11	8 5	E	0	93
2060		12	6 17	L	+ 7	94
2061		12	7 29	E, L	+ 2	94
2062		20	6 25	L	+15	102
2063		20	7 18	L	+13	102
2064		22	8 13	L	+21	104
2066		23	8 18	E, L	+25	105
2067		25	6 29	L	+53	0
2068		25	7 13	L	+62	0
2069		25	7 52	E, L	+60	0
2070		25	8 38	E	+65	0
2073	March	3	6 45	E	− 3	6
2077		4	7 59	E	− 3	7

A graphical representation of the values v of the radial velocity shows positive maxima on the following days, of which only the second is somewhat uncertain.

1903 January 19 = J. D. 2 416 134
December 6 = " 2 416 455
1906 November 10 = " 2 417 525
1907 February 25 = " 2 417 632

The intervals of the last three dates from the first are 321^d, 1391^d, 1498^d, or $3\times107^d.0$, $13\times107^d.0$, $14\times107^d.0$. The period of revolution is therefore

$$P = 107^d.0.$$

I would remark further that the observed values of v do not permit an aliquot part of $107^d.0$ as the possible period; $53^d.5$, or one-half of $107^d.0$, would require a maximum on 1904, December 14–15, which is contrary to the observations.

The observations show that the true value of the period can deviate from the value given by only a few hundredths of a day. This follows not only from the times of the observed maximum values of v, but also when the period is determined from certain points of the velocity-curve where its rise is steep.

If we now arrange the observations according to phase, it appears

that in consequence of the uncertainty of the measurements the observations at the same phase at times deviate pretty widely from each other. It therefore seemed advisable to me to form normal values, v_o, of the radial velocity by forming means from the observations taken at the same or closely related phases. For the phases 105^d to 0^d and 0^d to 2^d, observations at the same phase only were averaged, since the changes in v are here very large. For the others the values of v corresponding to the following values of Φ were formed into means v_o:

$\Phi = 3^d$ to 5^d	$\Phi = 27^d$ to 29^d	$\Phi = 63^d$ to 68^d
6 to 8	31 to 36	74 to 83
9 to 12	42 to 45	93 to 94
14 to 17	47 to 48	102
18 to 22	51 to 55	103 to 104

In averaging, the values of v which depend on the Mg line only, were given a weight $\frac{2}{3}$, the remainder a weight 1.

The spectrograms taken at $\Phi = 0^d$ all yielded values of v ($+53$ to $+65$ km) lying pretty near to the mean value ($+59.1$ km). None of these values differs from the mean more than the uncertainty of measurement would permit. Even the progression in the four values of v ($+53$, $+62$, $+60$, and $+65$ km), indicated on the evening of the last maximum, cannot be regarded as certainly real. I therefore made a simple assumption that the observations corresponding to $\Phi = 0^d$ were actually made at the time of maximum.

The following table contains the results of the computation of the normal values v_o of the radial velocity. The third column contains the number n of plates on which the value of v_o depends, and the last column contains the weight p.

Φ	v_o	n	p	Φ	v_o	n	p
0^d	$+59.1^{km}$	7	7	43^d	-3.2^{km}	4	$3\frac{1}{3}$
1	+19	1	1	48	−1.7	4	$3\frac{2}{3}$
2	+12	1	1	53	−7.0	3	$2\frac{2}{3}$
4	−2.3	3	3	66	−0.2	5	5
7	−1.3	3	3	77	−1.4	5	5
10	−6.8	4	4	94	+1.3	4	$3\frac{1}{3}$
15	−4.7	4	$3\frac{2}{3}$	102	+14.2	2	$1\frac{2}{3}$
19	−6.2	6	$5\frac{1}{3}$	104	+22.0	3	3
28	−5.8	5	5	105	+31.0	5	$4\frac{2}{3}$
34	−7.2	4	4	106	+41.0	3	3

In order to be able to employ the method of Lehmann-Filhés[1] for determining the orbit, the values of v_0 were platted as ordinates and those of Φ as abscissas in a rectangular system of co-ordinates, and a curve was drawn fitting the points thus obtained as closely as possible; this serves as the basis for the orbit. The radial velocity of the center of gravity of the system of *β Arietis* came out

$$V = -0.6 \text{ km}.$$

On the scale of the drawing ($1^d = 2$ mm; 1 km = 1 mm), the following values, expressed in square millimeters, were obtained:

$$z_1 = +128\,; \quad z_2 = -424\,.$$

We also have

$$A = 59.7 \text{ km}\,; \quad B = 5.5 \text{ km}\,.$$

In view of the uncertainty of the maximum value of v, A was taken in round numbers as 60 km.

By the formulae derived by Lehmann-Filhés I then found the following elements:

$$u_1 = 146^\circ.3\,,$$
$$\omega = 19^\circ.7\,,$$
$$e = 0.88\,,$$
$$\mu = 0.05872 = 3^\circ.364\,,$$
$$T = +0^d.1\,,$$
$$a \sin i = 22\,880\,000 \text{ km},$$
$$\frac{m_1^3 \sin^3 i}{(m+m_1)^2} = 0.042\ \odot\,.$$

Since the spectrum of only one component of *β Arietis* is visible, nothing further can be determined as to the masses than the ratio given above. If we assume $m = m_1$, we should have

$$m \sin^3 i = 0.17\ \odot\,.$$

For $i = 90^\circ$ we should therefore have $m = m_1 = 0.17\ \odot$, or the total mass of the system would amount to about one-third that of the sun.

I would add a few further remarks as to the computation of the elements. The radial velocity of *β Arietis* varies exceedingly slowly at the time when it has its largest negative value, so that the velocity-curve to that point runs almost parallel to the axis of abscissas. The consequence is that the determination of the phase to which the

[1] *Astronomische Nachrichten*, No. 3242, **136**, 17, 1894.

greatest negative ordinate B belongs is extremely uncertain. Hence z_2 was found by subtracting the quantity z_1 from the entire area below the axis of abscissas (after this had been displaced for the motion of the center of gravity.).

The eccentricity e was computed by the formulae of Lehmann-Filhés:

$$e \sin \omega = \frac{2\sqrt{AB}}{A+B} \cdot \frac{z_2+z_1}{z_2-z_1},$$

$$e \cos \omega = \frac{A-B}{A+B}.$$

The formula otherwise applicable for large eccentricities,

$$\sqrt{1-e^2} = \pi \tan u_1 \left\{ \frac{1}{2} - \frac{t_2-t_1}{U} \right\},$$

is hardly suited to the present case; since the time t_2 at which the radial velocity of the star equals, for the second time (reckoned from its maximum), the radial velocity of the center of gravity of the system, can be only very inaccurately determined on account of the very acute angle at which the velocity-curve cuts the axis of abscissas.

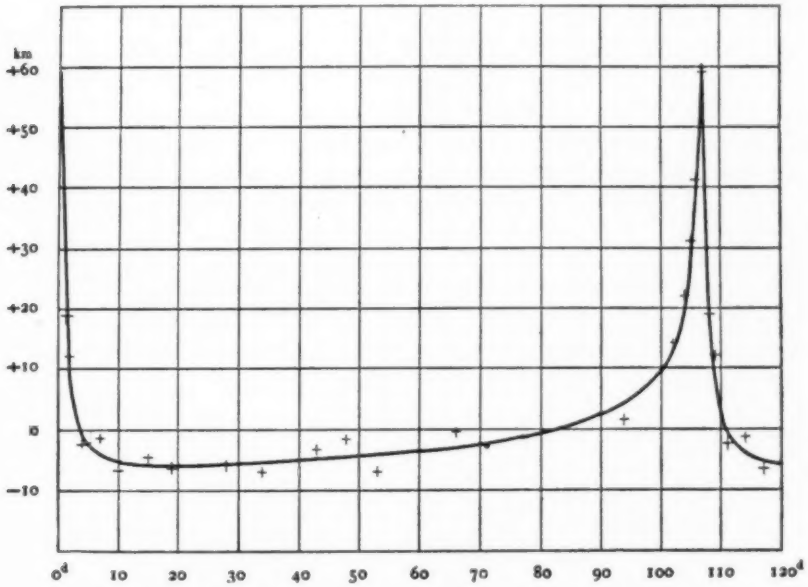
In order to test how well the elements represent the observations, I computed the following ephemeris. In so doing no attempt was made to give the fraction of a kilometer rigorously, which would be superfluous in view of the inaccuracies of the observations as well as of the elements.

Φ	v	Φ	v	Φ	v
0.0^d	+59.0^{km}	30^d	−5.8^{km}	95 ^{d}	+ 4.5^{km}
0.5	+43.9	35	−5.6	97.5	+ 6.5
1.0	+26.1	40	−5.3	100.0	+ 9.5
1.5	+13.8	45	−4.9	101.0	+11.0
2.0	+ 8.3	50	−4.5	102.0	+13.3
3.0	+ 2.4	55	−4.1	103.0	+16.3
4.0	− 0.7	60	−3.7	104.0	+20.7
5.0	− 2.4	65	−3.1	105.0	+27.6
7.5	− 4.5	70	−2.4	105.5	+33.3
10	− 5.3	75	−1.7	106.0	+42.3
15	− 6.0	80	−0.8	106.5	+53.3
20	− 6.1	85	+0.4	107.0	+59.0
25	− 6.0	90	+2.0		

The normal values v_0 of the radial velocity derived from the observations are represented as follows:

Φ	O.−C.	Φ	O.−C.	Φ	O.−C.
0d	+0.1km	19d	−0.1km	77d	−0.1km
1	−7.1	28	+0.1	94	−2.7
2	+3.7	34	−1.4	102	+0.9
4	−1.6	43	+1.9	104	+1.3
7	+2.8	48	+3.0	105	+3.4
10	−1.5	53	−2.7	106	−1.3
15	+1.3	66	+2.8		

The representation is entirely satisfactory, as systematic deviations nowhere strongly appear, and the values in general are also small. It is to be noted that the two largest differences (at $\Phi = 1^d$ and $\Phi = 2^d$) correspond to values of v_0 which depend on the measurement of only



Computed Velocity-Curve of *β Arietis* with normal values of velocity.

a single plate. The mean value for weight unity, i. e., for a plate on which the *Mg* line and $H\gamma$ were measured, comes out as ± 4.05 km. This value is not larger than would have been expected in advance from the character of the spectrum.

In view of what has been said, there is no occasion for undertaking a correction of the orbit until further observations have been obtained,

particularly such as will permit a sharper determination of the maximum velocity.

The figure gives a graphical representation of the ephemeris and of the normal values v_0 of the velocity. The unusual form of the velocity-curve is explained by the very great eccentricity of the orbit, and by the fact that the passage of the star through the ascending node nearly coincides with its passage through periastron.

The observations by no means exclude the possibility that A is somewhat larger than I have assumed it to be, in which case e would be larger than as given above. If, for instance, we take $A = 70$ km, and regard z_1 and z_2 as unchanged, which is tentatively permissible in view of the very pointed form of the curve near the maximum, we obtain:

$$u_1 = 148^\circ.7\,,$$
$$\omega = 18.1\,,$$
$$e = 0.90\,.$$

β Arietis has by far the greatest eccentricity of any spectroscopic binary of which the orbit is thus far known. *β Herculis* follows with an eccentricity of 0.55, and *ζ Ursae Majoris* with 0.52. Small eccentricities appear to predominate in general among spectroscopic binaries, in so far as such conclusions may properly be drawn from the slight amount of data at present available. For the twenty-six orbits of such systems at present known, including *β Arietis*, the eccentricities are distributed in the following way:

e	No.
0.00 to 0.15	15
0.16 to 0.30	3
0.31 to 0.45	2
0.46 to 0.55	5
>0.55	1

It should be mentioned further that Deslandres found $e = 0.60$ for the spectroscopic binary *θ Aquilae;* but the orbit seems to be very uncertain, and I therefore did not include that star in the above statistics.

Among visual binaries there are several having an eccentricity as great as, or even greater than, that of *β Arietis*. Aitken's "Catalogue of the Orbits of Visual Binary Stars"[1] gives for *γ Virginis*,

[1] *Lick Observatory Bulletin*, No. 84, 1905.

$e=0.90$; for Σ 2525, even $e=0.96$. The periods of these stars are, however, 194 and 307 years. Aside from these, eccentricities of 0.80 or over occurred in case of the binaries *γ Andromedae BC* ($e=0.82$, $P=55$ years), 99 *Herculis* ($e=0.81$, $P=65$ years), and *γ Centauri* ($e=0.80$, $P=88$ years). In these cases the systems are all of long period, while in the case of *β Arietis* the very large eccentricity is of particular interest especially in view of the shortness of the period.

ASTROPHYSIKALISCHES OBSERVATORIUM
Potsdam

A SPECTROGRAPHIC STUDY OF THE FOURTH-CLASS VARIABLE STARS *Y OPHIUCHI* AND *T VULPECULAE*[1]

By SEBASTIAN ALBRECHT

INTRODUCTION

On account of the extremely small displacements of spectrum lines, due to the radial velocities of the stars, it is desirable to use spectrographs of as high dispersion as possible. The amount of star light available is the principal factor in determining the upper limit of the dispersion. At present, determinations of the radial velocities of stars are made most extensively with three-prism instruments. These can be made to yield velocities reliable within a few tenths of a kilometer. The practicable limit of such an instrument, attached to the largest existing telescopes, is about the sixth photographic magnitude, which requires an exposure of approximately $2\frac{1}{2}$ hours. There is urgent need for a knowledge of the radial velocities of much fainter stars. Data for the solution of important astronomical problems by non-spectroscopic methods have been obtained from a large number of stars, some of which are as faint as the twelfth visual magnitude, whereas radial velocities have really been limited to the sixth photographic magnitude. The one-prism spectrograph of the Lick Observatory was employed by Dr. R. H. Curtiss in a study of the variable star *W Sagittarii*,[2] which varies between 5.5 and 6.5 photographic magnitudes. His work showed that good velocity determinations with the one-prism instrument could be obtained, at least when the exposures were comparatively short. His average exposure was about 30 minutes. It was definitely an object of the present investigation to test the efficiency of this spectrograph for much fainter stars, requiring long exposures. The average exposures for the two variable stars selected (*T Vulpeculae* and *Y Ophiuchi*) were 75^m and 180^m, respectively. The

[1] Thesis in partial fulfilment of requirements for the degree of doctor of philosophy in the University of California.

[2] *L. O. Bulletin*, **3**, 19, 1904; and *Astrophysical Journal*, **20**, 149, 1904.

latter star, of about the eighth photographic magnitude at minimum, may be considered the practicable limit for this instrument, attached to the 36-inch refractor. In the case of a star whose light is concentrated in a few spectrum lines or bands, it is of course possible to go several magnitudes lower. For example, the spectrum of *Nova Aquilae No. 2* was successfully photographed when the star was of the eleventh visual magnitude.

The dispersion of the one-prism spectrograph is one-fifth that of the three-prism Mills spectrograph. The average radial velocity of the brighter stars is about ±20 km per second. The equivalent displacement with the one-prism instrument, for the $H\gamma$ region, is 0.005 mm. A radial velocity of 2 km would produce a shift of 0.00002 inch (0.0005 mm). If the average radial velocity for the fainter stars is about the same[1] as for the brighter, then these small displacements are the quantities to be measured on the plates taken with the one-prism spectrograph. The results obtained are considered highly satisfactory. In the case of *Y Ophiuchi*, with an average exposure of 3 hours, the double amplitude of the velocity-curve is only 17 km. On the Mills spectrograms the same linear displacements would give a curve of $3\frac{1}{2}$ km double amplitude.

In addition to testing the possibility of extending the usefulness of the one-prism instrument for radial velocity work, it was thought that a contribution might be made toward the discovery of the causes of some of the peculiarities that are observed in short-period variable stars of the δ *Cephei* or η *Aquilae* type. Some of the more important points to be considered in this connection are: the peculiarities of, and the relation between, the light- and velocity-curves, peculiarities of the spectrum, changes in the character of the spectrum during the period of variability, and the behavior of the individual spectrum lines. The situation has been well described by Dr. Alexander W. Roberts.[2]

[1] Campbell's results seem to indicate that the velocities of the fainter stars are greater than those of the brighter stars.—*Astrophysical Journal*, **13**, 85, 1901.

[2] "Those whose researches lead them in one direction of an inquiry regarding the causes which underlie short-period variation must be impressed as well as oppressed, with the great area of uncertainty which surrounds the whole subject.

"At first sight we seem to know practically nothing of the immediate circum-

INSTRUMENT

With the exception of the addition of a temperature-case, the instrument used was the same as that employed by Curtiss in his study of *W Sagittarii* (*l. c.*). References in regard to description of the various parts of the instrument are given in that article. The iron spark, with sufficient self-induction to eliminate most of the air spectrum, was employed as the source of the comparison spectrum. The temperature-case was always put on the spectrograph between 30 minutes and an hour beforehand, in order to allow the greater part of the equalization of the temperature within the case to take place before beginning the exposure.

A PECULIARITY OF THE SPECTRA

In the variable stars of the *δ Cephei* type there is a greater richness of photographic radiation relatively to visual radiation at light-maximum than at light-minimum.[1] During the light-period the point of maximum energy on the energy-curve shifts along the spectrum, moving toward the shorter wave-lengths as the star approaches light-maximum, and back again toward the longer wave-lengths as light-minimum is approached. This fact is to a certain extent masked upon the spectrograms by instrumental and atmospheric causes, but in a long series it can readily be verified. My attention was first attracted to it by plate 13B (of *U Aquilae*), on which the region λ 4000 to λ 4200 was stronger than the *Hγ* region. I then

stances which produce variation of the definite type to which such stars as *η Aquilae* and *δ Cephei* belong.

"And yet the uncertainty is neither complete nor final. We are convinced, for example, that revolution and variation, or it may be rotation and variation, are connected together in some intimate relation, and that a solution of the problem of short-period variation will be obtained when we are able to declare what the nature and extent of this relation is.

"Any investigation, therefore, that purposes dealing with the measures of radial velocity obtained by spectroscopic observations must have a direct bearing on the wider problem of stellar variation. By considering the orbital movement of any binary system that also exhibits light-pulsations, we are approaching this problem from a less difficult and probably a more hopeful direction."—*Monthly Notices R. A. S.*, **66**, 329, 1906.

[1] The observations by Wilkens confirm this point. For five stars he finds the photographic range of brightness to be about one-half greater than the visual range.—*Astronomische Nachrichten*, **172**, 305, 1906.

examined all the spectrograms of *W Sagittarii* taken by Dr. R. H. Curtiss, and found the violet considerably weakened relatively to the green on the approach of light-minimum, the effect being greatest for this star between three and five days after light-maximum. The region from the H line to about λ 4200 is increased in intensity relatively to the blue and green as light-maximum is approached, and is apparently strongest at about 0.4 day after maximum.

The usual appearance of a spectrogram of a star of this type, taken on a Seed's Gilt Edge (27) plate, is a denser portion of about 300 Ångström units' length at λ 4600 or λ 4700, fading off slowly toward the violet and more rapidly toward the red. A combination of causes outside of actual changes in the star itself—such as differences in the transparency of the atmosphere, seeing, collimator setting, and emulsions—will somewhat modify this appearance. It is, therefore, not easy to determine from the spectrograms whether this shift of the point of maximum-energy along the energy-curve is entirely regular. The effect usually appears as a considerable intensification of the region λ 4000 to λ 4200, this region being then stronger than the *Hγ* region. On a few spectrograms it produced an almost uniform density of spectrum from the K line to λ 5000±. On plate 99B the effect is so marked that the possibility is not entirely excluded that it might have been due to a somewhat unusual outburst in the star. The plate falls close to periastron, though this may be accidental. Plates 35B of *T Vulpeculae* and 65A of *U Aquilae* show a similar appearance. 35B comes half a day after light-maximum, and 65A at maximum.

THE INDIVIDUAL SPECTRUM LINES

On account of the smallness of the dispersion, nearly all of the measurable lines on these spectrograms are blends of several components. One of the first points considered was the possibility that, for a few lines, some of the components might vary sufficiently during the light-period of the star to produce periodic shifts of measurable magnitude in their positions.[1] In this connection several factors

[1] Since then, variations in the positions of spectrum lines which are progressive from spectral type to type have been found by the writer on the spectrograms taken with the three-prism spectrograph of the Mills Observatory in Chile. (See *L. O. Bulletin*,

must be taken into account, the more important of which are the effect of varying amount of exposure, and the accuracy of measurement.

For the purposes of this study 39 lines were selected, and for each line the residuals (O.–C.)—i. e., the velocity given by the line minus the mean for all the lines measured on that plate—were formed and plotted from the measures of 34 spectrograms of *Y Ophiuchi*, arranged according to phase in the light-period. The same was done for 35 spectrograms of *T Vulpeculae*. Nine spectrograms of *Y Ophiuchi* and fifteen of *T Vulpeculae* were represented by double measures, the second measures having been made at times varying from a day to two years after the first measures. Each measure was made with violet to the left and violet to the right. The 24 spectrograms that are represented by double measures include overexposures and underexposures, and plates on which the star lines are quite fuzzy. In quality they are below the average of all the plates, and the measurements were made under varying conditions of illumination. They furnish, therefore, a severe test of the accuracy of measurement.

Following are the results briefly summarized. The probable error of measurement of a single line, as obtained from these double measures, was found to be ± 2.0 km. For only 8 per cent. of the lines did the second measure differ from the first by more than 10 km, and the greatest difference found was 23 km. The greatest error of measurement was therefore 12 km. If to the 23 km be added twice the largest error of a plate, we see that the greatest total range, on all the plates, of any individual spectrum line should be about 30 km (i. e., 15 km on each side of the zero position). The best lines should not have a range greater than half that amount. Nevertheless, the actual range averaged more than 30 km, and in several cases was as high as 50 km. A line, which from all external appearances should not differ from its zero position by more than 6 or 8 km, would occasionally differ from that position by 25 km. Almost invariably the second measure would reproduce the first within a few kilometers.

No. 106, and *Astrophysical Journal*, **24**, 333, 1906.) Also, a preliminary study of the the high-dispersion spectrograms of η *Aquilae* showed very strong indications of just such variations in the positions of certain lines as were looked for on these low-dispersion plates of *Y Ophiuchi* and *T Vulpeculae*.

The following residuals (in km), obtained from the first and second measures of plate 53A, illustrate this point (only the lines that were included in both measures are here given): $-3, +4$; $-1, -1$; $-7, -3$; $-9, -7$; $+4, +2$; $+25, +24$; $-5, -2$; $-2, -2$; $+10, +11$; $-7, -5$; $-21, -19$; $+20, +11$; $+9, +7$; $-21, -23$; $+6, -3$; $-9, -17$; $-4, -5$; $+8, +11$; $-3, -5$; $+3, -1$. The line giving the residuals $+25$ and $+24$ km, on the first and second measures respectively, is to all appearances one of the best lines on the plate. On the thirty other spectrograms of the same star on which the line was measured the residuals range between $+10$ and -11 km. The relative displacement of this line on plate 53A is without doubt real, though the cause of the shift is uncertain. There is no evidence of any distortion of the film. This region of the plate is somewhat underexposed, and it was at first believed that this would account for the broadening of the line. Several other plates on which the exposure is about the same as on plate 53A, and some that are more underexposed, do not show the broadening. This is only one of a considerable number of similar examples.

Suffice it to state that no definite trace of a shift of any of the lines was found which is progressive with the phase of the star in its light-period. Large shifts in the positions of many lines were found, which seemed to be more or less of an accidental nature. For the present the question will be left in abeyance as to whether or not these irregular changes in the positions of some of the lines are due entirely to causes outside of the star.

THE VARIABLE STAR *Y OPHIUCHI*

The variable brightness of *Y Ophiuchi* was discovered by Sawyer in 1888. The principal data taken from the Chandler and Harvard Catalogues are as follows:

Chandler's Third Catalogue

α, 1900.0, $= 17^h\ 47^m.3$, δ, 1900.0, $= -6°\ 7'$. Visual magnitudes 6.2 to 7.0. Period 17.1207 days. Epoch of maximum 1882 Sept. 5; *J. D.* 2408694.25.

Harvard Catalogues

Visual magnitudes 6.1 to 6.5; Class IV; Sp. *G*.

Three hundred and nine observations by Luizet[1] in the years 1898 to 1904 were found to satisfy Hisgen's elements given in Chand-

[1] *Astronomische Nachrichten*, **168**, 351, 1905.

ler's Third Catalogue. Luizet gives the visual magnitudes as 5.9 to 6.6. The observations for the light-variations fortunately extend to within a year of the spectrographic observations that are discussed in this paper. My measures of the first eight spectrograms showed a variable radial velocity, the total range of variation being, however, small.[1] Table I gives the more important data in regard to the spectrograms of this variable.

After several trials of various ellipses with different values of the elements, the velocity-curve shown in Fig. 1 (the continuous line) was selected. The lower part of the figure shows the light-curves due to Pickering and Luizet. The elements upon which the velocity-curve is based are:

$$U = 17.1207 \text{ (light-period)},$$
$$\mu = 21^\circ.026,$$
$$T = 2.6 \text{ days after light-maximum},$$
$$\omega = 209^\circ.2,$$
$$K = 8.5 \text{ km (single amplitude)},$$
$$e = 0.10,$$
$$V = -5.0 \text{ km (velocity of system)},$$
$$a \sin i = 1{,}999{,}000 \text{ km}.$$

There is some indication of an irregularity in the velocity-curve. If a secondary curve with a period equal to half the light-period and a double amplitude of 2.5 km be superimposed upon the elliptic curve given above, the curve represented by the discontinuous line in the upper part of Fig. 1 results. This curve gives a better representation of the observed velocities except between zero and two days after light-maximum, where there is no choice either way. If we remember that the velocity for plate 10E is based on only eight lines, and should therefore be given small weight, we see that the improvement is very decided along the stretch from 3 to 7 days after light-maximum. Likewise, between 11 and 13 days the points corresponding to plates 27A and 59A should be given smaller weight than the points above the curve. This irregularity is such an extremely small quantity for the dispersion employed that we cannot place entire confidence in its reality. It would be equivalent to obtaining a secondary curve of 0.5 km double amplitude with the three-prism

[1] *Pub. A. S. P.*, **18**, 66, 1906.

Mills spectrograph. Attention is called to the fact that the light-curve shows a similar irregularity.

More prominent irregularities in velocity-curves have been observed by Campbell[1] in *ζ Geminorum* and by R. H. Curtiss in *W Sagittarii*

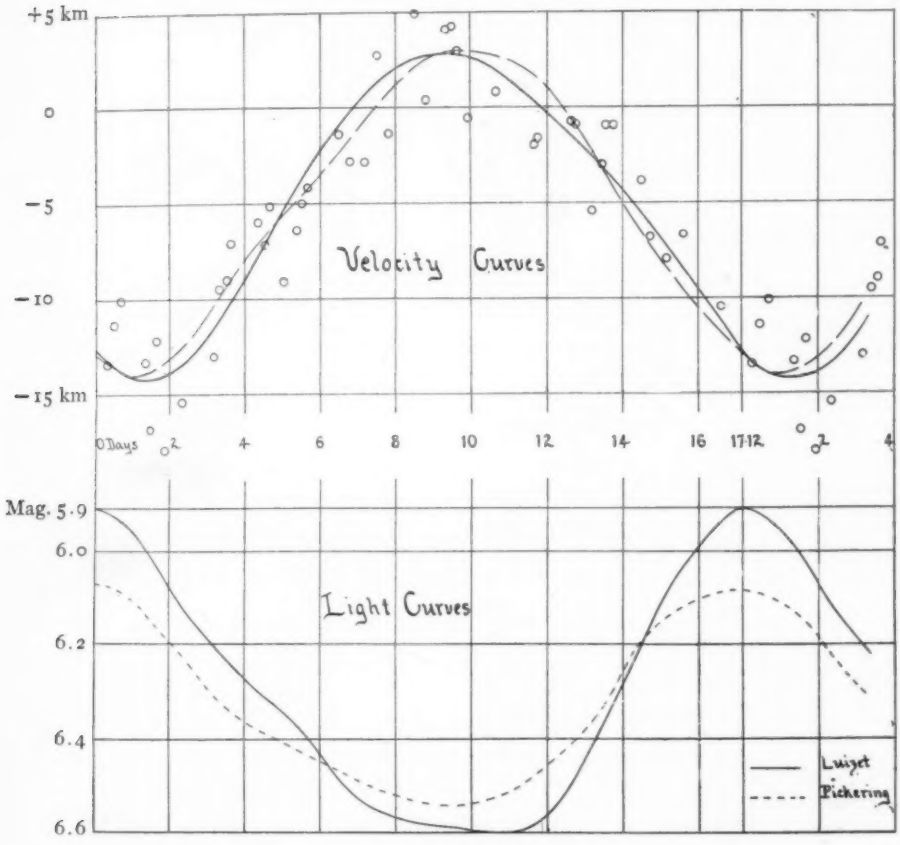


FIG. 1.—*Y Ophiuchi*

(*l. c.*). The cause of these secondary curves is still an unsettled question. Various explanations have been offered, such as the presence of a third body; the rotation of the brighter component; a resisting medium; or the effects of tidal forces, which must necessarily be large in such close binaries. Dr. Alexander W. Roberts

[1] *Astrophysical Journal*, **13**, 90, 1901.

TABLE I

V OPHIUCHI

Plate	Date of Mid-Exposure. G. M. T.	Interval since Maximum	v_s	Reduction to Sun	V	No. of Lines	Duration of Exposure	Slit-Width	Seeing	Character of Spectrogram, etc.
	1905	Days	km	km	km		min.	In units of 0.025 mm		
1D	May 10.986	13.438	−20.0	+17.0	− 3.0	28	120	1.4	Fair	Fair. Underexposed.
10E	June 5.812	5.022	−15.3	+ 6.1	− 9.2	8	240	1.4	V. bad	Much underexposed.
12A	July 11.830	6.799	+ 8.1	−10.9	− 2.8	22	150	1.4	Poor	Underexposed. Much smoke in air.
14A	12.843	7.812	+10.0	−11.4	− 1.4	25	240	1.4	Poor	Good.
15B	13.823	8.792	+12.1	−11.7	+ 0.4	43	180	1.4	Fair	Good.
16A	16.797	11.766	+11.3	−12.9	− 1.6	29	180	1.4	Good to fair	Fair.
17A	17.778	12.747	+12.5	−13.4	− 0.9	34	170	1.4	Fair	Good. Much smoke in air.
18A	18.782	13.751	+12.9	−13.8	− 0.9	26	150	1.4	Good to fair	Fair.
19A	19.790	14.759	+ 7.5	−14.2	− 6.7	38	150	1.4	Fair	Good.
20A	22.785	0.633	+ 5.4	−15.5	−10.1	31	130	1.4	Fair	Good.
21A	23.799	1.647	+ 3.7	−15.9	−12.2	27	150	1.4	Poor	Underexposed Thin clouds.
22A	25.762	3.610	+ 9.5	−16.6	− 7.1	41	180	1.4	Poor	Fair.
23A	26.773	4.621	+11.8	−17.0	− 5.2	30	195	1.4	Poor	Underexposed. Fair.
24A	27.789	5.637	+13.2	−17.4	− 4.2	32	200	1.4	Poor	Good. Wind 30 miles N. W.
25A	31.710	9.558	+21.9	−18.9	+ 3.0	26	180	1.4	Poor	Much smoke in air. Underexposed.
26A	Aug. 1.762	10.610	+20.0	−19.2	+ 0.8	35	180	1.4	Poor	Good.
27A	2.76	11.61	+17.5	−19.5	− 2.0	22	190	1.4	Poor	Underexposed.
28A	3.769	12.617	+19.2	−19.9	− 0.7	37	200	1.4	Fair	Somewhat underexposed. Good.
29A	6.749	15.597	+14.3	−20.9	− 6.6	38	160	1.4	Good	Good.
30A	7.740	16.588	+10.8	−21.2	−10.4	38	150	1.4	Fair	Good.
31A	8.751	0.479	+10.2	−21.5	−11.3	41	140	1.4	Fair	Good.
32A	9.747	1.475	+ 4.9	−21.8	−16.9	36	150	1.4	Good	Good. Exposure cut off for 20 min.
33A	11.810	3.538	+13.4	−22.4	− 9.0	28	210	1.4	Poor	Somewhat underexposed. Good.
34A	12.808	4.536	+15.6	−22.8	− 7.2	25	160	1.5	Poor	Smoke in air. Wind 30 miles. Unexposed.
36A	13.758	5.486	+18.0	−23.0	− 5.0	33	210	1.4	Fair	Good. Sky good.

TABLE I—*Continued*

Plate	Date of Mid-Exposure. G. M. T.	Interval since Maximum	v_s	Reduction to Sun	V	No. of Lines	Duration of Exposure	Slit-Width	Seeing	Character of Spectrogram, etc.
	1905	Days	km	km	km		min.	In units of 0.025 mm		
37A	Aug 14.740	6.468	+21.9	−23.3	− 1.4	30	180	1.5	Poor	Good. Sky good.
38A	15.754	7.482	+26.3	−23.6	+ 2.7	22	210	1.5	Good	Image of star faint. Thin clouds. Underexposed. Fair.
39A	16.764	8.492	+28.7	−23.8	+ 4.9	17	190	1.4	Poor	Haze. Underexposed and somewhat fuzzy.
40A	17.746	9.474	+28.4	−24.1	+ 4.3	28	200	1.4	Fair	Underexposed. Fair.
41A	21.832	13.560	+24.2	−25.1	− 0.9	32	205	1.4	Fair	Good. Somewhat underexposed.
42A	22.738	14.466	+21.5	−25.3	− 3.8	36	180	1.4	Fair	Good.
43A	25.736	0.343	+12.5	−25.9	−13.4	37	180	1.4	Good	Good. Clouds passed over star occasionally.
44A	26.772	1.379	+12.9	−26.2	−13.3	29	160	1.4	Fair	Good.
45A	27.726	2.333	+10.9	−26.3	−15.4	38	150	1.4	Good	Good.
47A	28.724	3.331	+17.0	−26.5	− 9.5	35	166	1.4	Good	Good.
49A	29.765	4.372	+20.7	−26.7	− 6.0	28	200	1.4	Poor	Sky fair. Wind 30 miles at end of exposure. Fair.
50A	30.774	5.381	+20.5	−26.9	− 6.4	31	210	1.4	Fair to poor	Much smoke in air. Underexposed. Fair.
51A	Sept. 3.751	9.358	+31.6	−27.5	+ 4.1	11	210	1.4	Poor	Much smoke in air. Very much underexposed.
53A	14.706	3.192	+15.4	−28.4	−13.0	27	190	1.4	Fair	Good. Somewhat underexposed.
54A	18.698	7.184	+25.7	−28.5	− 2.8	11	180	1.4	Fair	Poor. Very much underexposed.
59A	24.699	13.185	+23.1	−28.5	− 5.4	20	190	1.5	Poor	Much underexposed.
63A	26.682	15.168	+20.5	−28.4	− 7.9	28	190	1.5	Fair	Fair. Underexposed.
	1906									
112B	Aug. 12.733	9.926	+22.1	−22.6	− 0.5	12	180	1.5	Poor	Very much underexposed.
121A	21.725	1.797	+ 6.8	−24.8	−18.0	31	170	1.5	Poor	Somewhat underexposed. Fair.

has shown, in the interesting article referred to above, that considerable deviations of the principal bodies from the spherical form, in the case where the size of the stars is distinctly comparable to the size of their orbits, would give rise to a secondary period in the velocity-curve equal to half the primary period. This is a very interesting and suggestive explanation, though probably not a complete one. In *W Sagittarii* the secondary period is without doubt half that of the primary, whereas in the case of ζ *Geminorum* a secondary period, equal to one-third that of the primary, satisfies the observed curve better than one of half the primary period. In a complete explanation probably a number of factors must be taken into account, and in the different individual cases one or the other of these factors may become the predominant one, and thus produce differences in the period of the secondary or in other peculiarities of this class of variables. In the course of a few years, as studies of several other variables of this and related classes will become available, we may hope to be able to speak more authoritatively in regard to the characteristics that are common to all as well as the points of difference. In individual cases we may be able to pick out the predominant influences that are at work.

THE VARIABLE STAR *T VULPECULAE*

The variable brightness of *T Vulpeculae* was discovered by Sawyer in 1885. The principal data taken from the Chandler and Harvard Catalogues are as follows:

Chandler's Third Catalogue

α, 1900.0, $=20^h\ 47.^m2$; δ, 1900.0, $=+27^\circ\ 52'$.
Redness 0; visual magnitude 5.5 to 6.5
Period 4.4360 days; epoch 1885, Nov. 2, *J. D.* 2409848.95
Basis of elements, observations 1885–95.

Harvard Catalogues

Visual magnitudes 5.5 to 6.2; Class IV; Sp. *F.*

Light-curves for this variable have been obtained by Sawyer, Chandler, Yendell, Pickering, Luizet, and Terkán by visual methods, and by Wilkens by a photographic method. From observations made in 1898 and 1899 Luizet derives the following elements: period 4.43578 days; epoch of maximum *J. D.* 2409849.02 (1885, Nov. 3.02). These values of period and epoch were adopted in this

investigation. They differ but slightly from the values given in Chandler's Third Catalogue. The series of photographic observations for the determination of the light-curve made by Wilkens from July 9 to September 18, 1905, are practically simultaneous with the principal series of the spectroscopic observations. This is a very fortunate circumstance.

The binary character of the star was announecd by Frost.[1] Before the announcement appeared our first series of spectrograms of the star had been obtained by Drs. H. D. Curtiss and Moore. The following data were given in regard to Frost's two observations:

Plate	Date	G. M. T.	No. of Lines	Radial Velocity
1B 379	1904, July 19	$20^h\ 5^m$	9	+15km
385	22	19 47	13	−17

These two observations fall on opposite sides of my curve, the first 11 km above and the second 3 km below it. In the figure they are represented by the crossed circles. The large residual is probably due to the small number of lines measured. Table II gives the more important data in regard to the spectrograms of this star that were obtained. When taken by others than the writer, the observer's initials are given in the column of remarks. All of the measures were made by the writer.

The solution of the orbit was made by the method of Lehmann-Filhés. After several trials of various ellipses with different values of the elements, the velocity-curve computed with the elements given below was found to reproduce the observed velocity-curve well within the error of construction of the latter. A least-square solution was therefore considered entirely unnecessary. The following are the adopted elements:

$U = 4^d.43578$ (light-period),
$\mu = 81°.1583$,
$T = 3^d.76$ after light-maximum,
$\omega = 111°$,
$K = +17.6$ km (single amplitude),
$e = 0.43$,
$V = -1.3$ km (velocity of system),
$a \sin i = 969{,}180$ km.

[1] *Astrophysical Journal*, **20**, 296, 1904.

TABLE II.—*T VULPECULAE*

Plate	Date G. M. T.	Interval since Maximum	v_s	Reduction to Sun	V	No. of Lines	Duration of Exposure	Slit-Width	Seeing	Character of Spectrogram, etc.
	1904	Days	km	km	km		min.			
3339E	July 12.967	3.717	−19.9	+11.7	− 8.2	31	46	1.4	Good	Good. Taken by H. D. C.
3355D	24.931	2.374	+ 7.4	+ 7.9	+15.3	17	85	1.2	Fair	Violet very much underexposed. Taken by H. D. C.
3391E	Aug. 9.947	0.647	−11.1	+ 2.3	− 8.8	23	111	1.3	Fair to poor	Overexposed. Taken by H. D. C.
3395D	15.930	2.194	+ 5.4	+ 0.1	+ 5.5	27	80	1.3	Fair	Taken by H. D. C.
3415D	29.915	2.872	+15.6	− 4.9	+10.7	25	120	1.4	Good	Good. Somewhat overexposed. Taken by H. D. C.
3471C	Oct. 2.793	1.264	+10.2	−15.7	− 5.5	37	95	1.4	Poor at times	Fair. Taken by J. H. M.
3495A	18.798	3.961	+ 1.0	−19.3	−18.3	30	60	1.3	Poor	Good. Taken by H. D. C.
	1905									
35B	Aug. 12.952	0.483	− 8.0	+ 1.3	− 6.7	37	111	1.4	Fair to poor	Good. Taken by J. H. M.
46B	27.873	2.096	+13.6	− 4.1	+ 9.5	31	80	1.4	Good	Good.
48B	28.828	3.051	+19.9	− 4.3	+15.6	33	95	1.4	Good to fair	Good.
55B	Sept. 18.810	1.854	+19.7	−11.5	+ 8.2	37	90	1.4	Good	Good.
60B	24.834	3.443	+22.0	−13.4	+ 8.6	25	80	1.5	Poor to fair	Good. Somewhat underexposed.
64A	Oct. 3.720	3.457	+22.4	−15.7	+ 6.7	22	90	1.4	Fair	Good. Slightly overexposed.
66B	4.790	0.091	− 0.4	−16.2	−16.6	33	65	1.4	Fair	Good.
68E	5.828	1.129	+17.6	−16.4	+ 1.2	34	70	1.4	Good	Good. 4° difference between t_1 and t_3
70E	9.776	0.641	+ 7.6	−17.2	− 9.6	26	70	1.4	Fair	Good. *Fe* overexposed.
75E	17.800	4.230	− 1.9	−19.1	−21.0	18	70	1.4	Fair	Good.
76A	19.662	1.656	+24.4	−19.2	+ 5.2	17	80	1.4	Good	Good.
78E	20.776	2.770	+35.0	−19.6	+15.4	18	95	1.4	Poor	Fair. Somewhat underexposed.
79E	21.642	3.636	+ 9.7	−19.5	− 9.8	22	60	1.5	Good	Overexposed.
81B	23.761	1.319	+18.6	−20.1	− 1.5	20	70	1.4	Good	Fair.
82E	24.705	2.263	+26.5	−20.1	+ 6.4	29	100	1.4	Good	Fair.
83E	25.679	3.237	+36.2	−20.2	+16.0	38	100	1.4	Good	Star spt'm good. *Fe* poor on one side.
84B	27.646	0.768	+12.4	−20.5	− 8.1	40	60	1.4	Good	Good. Somewhat overexposed.
85E	27.706	0.828	+16.7	−20.6	− 3.9	24	67	1.4	Good	Some clouds? Good.
87E	Nov. 2.700	2.386	+30.7	−21.3	+ 9.4	27	90	1.4	Fair	Fair. Somewhat underexposed.
88E	5.662	0.913	+16.4	−21.5	− 5.1	20	90	1.6	Poor	Good, but grain of plate is bad.
89E	7.609	2.860	+32.9	−21.5	+11.4	24	90	1.4	Fair	Fair. Somewhat overexposed.
91E	9.684	0.499	+ 8.6	−21.8	−13.2	17	68	1.4	Good	Clouds came over. Poor; intensity drops off rapidly toward violet.
92B	10.622	1.437	+21.0	−21.7	− 0.7	26	60	1.6	Poor	Fair. Smoke in air.

TABLE II.—*Continued*

Plate	Date G. M. T.	Interval since Maximum	v_s	Reduction to Sun	V	No. of Lines	Duration of Exposure	Slit-Width	Seeing	Character of Spectrogram, etc.
	1905	Days	km	km	km		min.			
93B	Nov. 13.635	0.014	+ 2.9	−21.9	−19.0	22	62	1.5	Poor	Passing clouds. Wind 28 miles. Good exposure but spectrum somewhat fuzzy.
94B	14.610	0.989	+14.3	−21.9	− 7.6	40	62	1.4	Fair	Fair. Underexposed.
95B	21.622	3.565	+17.7	−21.9	− 4.2	35	70	1.6	Poor	Fair. t_3 went up continuously.
97B	Dec. 1.621	0.257	+ 9.1	−21.3	−12.2	25	80	1.4	Poor	Fair.
98B	4.617	3.253	+30.1	−20.9	+ 9.2	25	62	1.4	Fair	Exposure gradually shut off by clouds. Underexposed. Fair.
99B	9.606	3.809	+ 7.0	−20.3	−13.3	26	99	1.6	Poor	Wind 30–40 miles. Density uniform from K line to λ5000±.
103B	31.593	3.614	+10.0	−15.7	− 5.7	8	59	1.5	Poor	Star spectrum fuzzy. Underexposed. $t_1 = -3°$.
	1906									
104B	Jan. 4.618	3.204	+25.4	−14.6	+10.8	24	66	1.5	Fair to poor	Underexposed.
106A	Aug. 5.743	3.411	+ 7.1	+ 4.3	+11.4	31	80	1.4	Good to fair	Good.
107B	5.799	3.467	+ 6.7	+ 4.1	+10.8	40	74	1.4	Good	Good.
108A	5.910	3.578	− 4.3	+ 3.9	− 0.4	35	74	1.4	Good	Good.
109B	5.962	3.630	− 7.6	+ 3.8	− 3.8	29	74	1.4	Fair	Good.
110A	9.880	3.112	+ 9.7	+ 2.6	+12.3	30	94	1.4	Good to fair	Clouds interfered during last half hour. Somewhat underexposed.
111B	9.952	3.184	+11.0	+ 2.4	+13.4	32	96	1.4	Fair	Clouds interfered considerably. Somewhat underexposed.
113A	19.692	4.053	−22.2	− 0.6	−22.8	23	74	1.4	Fair	Good. No heating current.
114B	19.754	4.115	−20.6	− 0.8	−21.4	37	64	1.4	Fair	Good. No heating current.
115A	19.859	4.220	−18.9	− 1.0	−19.9	24	60	1.4	Fair	Good. Heating current available again.
116B	19.942	4.303	−16.7	− 1.1	−17.8	27	60	1.4	Fair	Good.
117A	20.703	0.628	− 8.9	− 1.0	− 9.9	37	76	1.4	Fair to poor	Wind 25 miles. t_3 went up without heating current. Good.
118B	20.757	0.682	− 6.3	− 1.1	− 7.4	32	76	1.4	Poor	Wind 25 miles. Good.
119A	20.833	0.758	− 4.0	− 1.3	− 5.3	31	80	1.4	Poor	Wind 25 miles. Good.
122B	21.842	1.767	+ 6.5	− 1.6	+ 4.9	30	86	1.4	Poor	Lens fogged? Somewhat underexposed

For each star the probable error of a single plate was found to be ±1.2 km. The probable error of measurement of a single spectrum line was ±2.0 km. From this alone we should expect a smaller

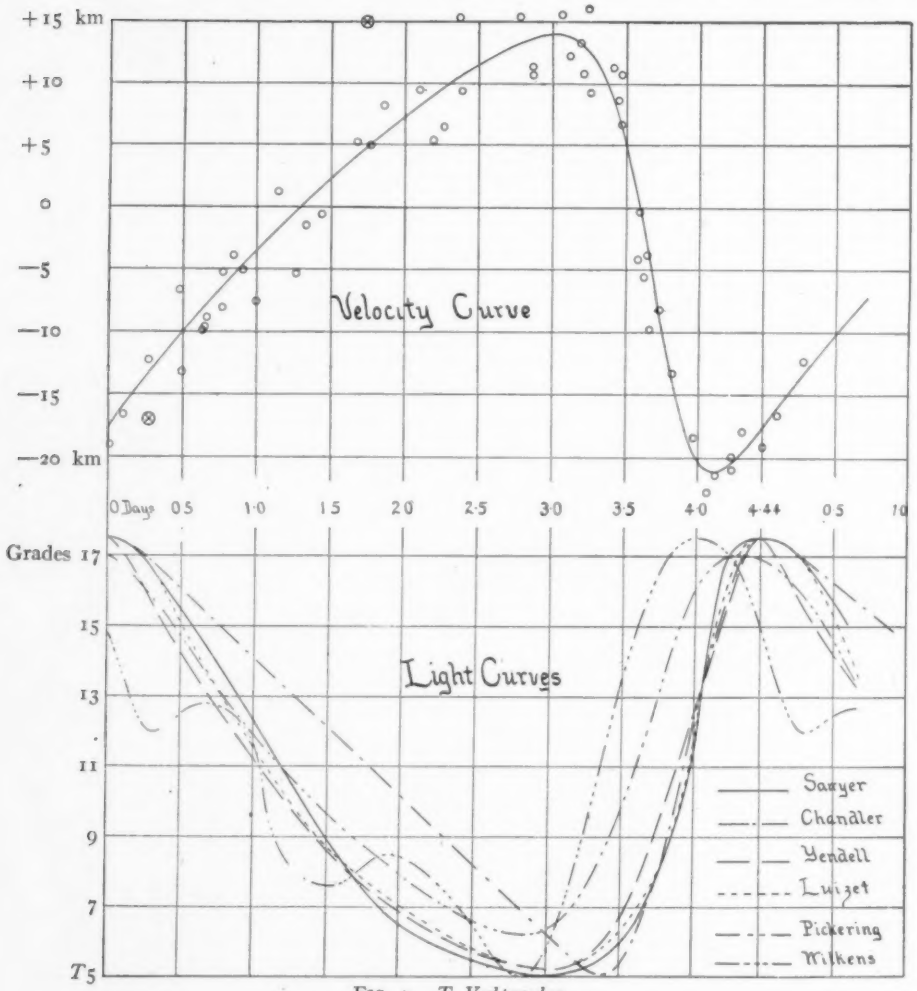


FIG. 2.—*T Vulpeculae*

value for the probable error of a plate. If we remember, however, that large accidental variations in the positions of individual lines were not uncommon (see p. 334), the value found for the probable error of a plate is readily accounted for. Also, in such long exposures as

were employed on these variables, the chances become greater for an incomplete correspondence between the star- and the comparison-spectra.

The upper part of Fig. 2 shows the velocity-curve computed with the elements above, while the lower part of the figure gives the light-curves by several observers. For Pickering's light-curve the range of variation is smaller than for the other observers. For Wilkens' photographically determined light-curve the photographic range of variation was reduced to the visual range by his ratio of photographic to visual range, which for this star was 1.5. The visually determined light-curves agree fairly well in regard to the epoch of maximum. The origin of the minor differences between these curves is not entirely clear. Luizet,[1] who compared his own curve with those of Chandler, Sawyer, and Yendell, ascribed the differences between them to a sort of personal equation. Wilkens' light-curve, determined by a photographic method, gives the epoch of maximum 0.4 day earlier than the curves which were determined by visual methods. A longer series of photographic observations is desirable to establish definitely this apparent difference between the times of maximum brightness for the visual and photographic radiations. Wilkens has drawn two secondary maxima and minima in his light-curve for this star. The curve is based on seventeen observations, which, of course, cannot be considered sufficient to establish these irregularities. My velocity-curve does not definitely show corresponding irregularities, nor does it prove their non-existence. They could be drawn in approximately the positions indicated by Wilkens, and this would reduce the residuals somewhat. One important point in connection with the velocity-curve is that it depends upon three series of observations, in three successive years, and that each series is satisfied by the same curve. There is thus no appreciable rotation of the line of apsides nor rapid change of any of the other elements.

In neither of these two stars could the variability be due to an eclipse, for in that case maximum and minimum brightness would occur at the points where the velocity equals the velocity of the system.

Perhaps the most important result of this investigation is the conclusive evidence of a much closer relationship between the light- and

[1] *Astronomische Nachrichten*, **153**, 80, 1900.

TABLE III.

Star	Period	Time Interval between Maximum Brightness and Greatest Negative Velocity	Observer	Reference
	Days	Days		
ζ Geminorum	10.15	+0.2	W. W. Campbell at L. O.	*Astrophysical Journal*, **13**, 90, 1901
η Aquilae	7.18	+0.2	W. H. Wright at L. O.	*Ibid.*, **9**, 59, 1899
δ Cephei	5.37	−0.2±	A. Belopolsky at Pulkowa	*Ibid.*, **1**, 160, 1895
W Sagittarii	7.60	+0.1	R. H. Curtiss at L. O.	*Ibid.*, **22**, 274, 1905
T Vulpeculae	4.44	−0.3	S. Albrecht at L. O.	This article
Y Ophiuchi	17.12	+1.3±	S. Albrecht at L. O.	This article
U Aquilae	7.02	+0.5±	S. Albrecht at L. O.	Not published
X Sagittarii	7.01	+0.3±	J. H. Moore at L. O.	Not published
S Sagittae	8.38	0. ±	R. H. Curtiss at L. O.	*L. O. Bulletin* 62
S U Cygni	3.85	+0.5±	J. D. Maddrill at L. O.	*Publ. A. S. P.*, **18**, 252, 1906

velocity-curves than has heretofore been believed to exist. If the light is sent out equally in all directions from the variable star, the positions of light- and velocity-maxima and minima should bear no special relation to each other, for the brightness would be independent of the direction from which the star is observed, while the radial velocity at any instant is dependent upon the direction of the observer. For different stars we should, therefore, expect the two curves to be shifted by different amounts relatively to each other around the period. For some stars greatest positive velocity would come at light-maximum, in others at light-minimum, and in most cases at other points along the light-curve. Table III of the ten variables of this class for which both light- and velocity-curves are available, shows that light-maximum and most rapid approach always occur together. Likewise, there is a time-correspondence between minimum brightness and greatest velocity of recession. We should therefore also expect that when irregularities[1] exist in both light- and velocity-curves, they will correspond to each other in position and perhaps also in shape. Of the ten stars in the above list only two have thus far shown marked irregularities in both light- and velocity-

[1] All the irregularities observed in the brightness- and velocity-curves of the stars contained in Table III fall between light-maximum and light-minimum, except in the case of *ζ Geminorum*.

curves. They are *W Sagittarii*[1] and *Y Ophiuchi;* and for these the irregularities in the two curves correspond very closely.

This establishes the fact that in the variable stars of the δ *Cephei* type the light- and velocity-variations are very intimately connected; that both are due to the same causes; and that, if the velocity-variation is dependent upon the direction of the observer, so also must the observed light-variations be dependent upon the same factor.

At present the best theory for this class of variables seems to be that they are binaries, in which one of the component stars is considerably brighter than the other. The observed velocity-variation follows mainly as a direct consequence of the orbital motion of the brighter component. The light-variation seems to be caused in some way (other than eclipse) by the influence of the darker companion. The very close correspondence between the light- and velocity-curves in regard to period and shape, and the agreement of the times of occurrence of maximum brightness with greatest velocity of approach and minimum brightness with greatest velocity of recession, would indicate that the light-variation is not so much dependent upon the position of the brighter component of the system in its orbit as upon the direction from which the star is observed. This would ascribe less direct influence to the darker companion in the matter of liberating an unusual amount of energy in a certain part of the orbit, most likely a small fraction of the period after periastron passage. Dr. Campbell has called my attention to the fact that the *Algol* variables, which are binaries of even shorter average period than the δ *Cephei* variables, show no evidence of light-variation other than that caused by eclipse, and that the apparent failure of two *Algol* components to disturb each other should make us careful in ascribing the total observed effects in δ *Cephei* variables to the mutual disturbing powers of the components. Most of the eclipse variables have earlier-type spectra (*B*, *A*, and *F*) than the variables of Class IV. It is not impossible that in close binary pairs having the simpler types of spectra (*Algol* variables) the mutual disturbances are less effective in producing brightness-variations than in close pairs having older types of spectra (δ *Cephei* variables).

[1] *Astrophysical Journal*, **22**, 274, 1905.

SUMMARY OF RESULTS

1. With the one-prism spectrograph and 36-inch refractor, we can obtain satisfactory radial velocities of stars of the eighth photographic magnitude, requiring exposures of three hours, provided their spectra contain well-defined lines.

2. For several variables of the δ *Cephei* or η *Aquilae* type it was found that the point of maximum energy in the spectrum is shifted toward the violet as light-maximum is approached, and back again toward the red as the brightness diminishes. From the spectrograms it was impossible to decide whether or not this shift of the point of maximum energy occurs with absolute regularity.

3. On these low-dispersion spectrograms no periodic shift in the position of any of the lines (blends) was found.

4. Velocity-curves and orbits for the fourth-class variable stars *Y Ophiuchi* and *T Vulpeculae* were obtained.

5. A comparison of the light and velocity-curves of the ten variables of this class for which both curves are available showed a much closer relation to exist between the light- and velocity-variations than has heretofore been supposed to be the case. In every observed case, light-maximum and greatest velocity of approach occur within one-fifteenth of the period of each other. Likewise minimum brightness and greatest velocity of recession occur at the same time. That is, the two curves have a very close correspondence in phase, in addition to correspondence of shape and period. If the velocity-curves were plotted with negative values above and positive below, the brightness- and velocity-curves for any star, if constructed on the proper scale, would be almost identical. The time-interval from maximum to minimum brightness is on the average about double the interval from from minimum to maximum brightness.

It is with great pleasure that I acknowledge my indebtedness to Dr. Campbell for the continued interest he has taken in this investigation. In assigning stars of the δ *Cephei* type as subjects for theses to several successive candidates for the degree of doctor of philosophy, he had definitely in mind the determination of the characteristics of these variables as a class, through the observations of a large number of these stars, as a basis for safe reasoning upon the cause or causes of their variability.

LICK OBSERVATORY
UNIVERSITY OF CALIFORNIA
May, 1907

ON THE DISTORTIONS OF PHOTOGRAPHIC FILMS ON GLASS[1]

By SEBASTIAN ALBRECHT

INTRODUCTION

In various lines of astronomical research depending upon photographic plates, discrepancies of a considerable magnitude occasionally appeared, which seemed attributable to no definite cause. On the star-photographs taken with the Crossley Reflector, these occasional discrepancies, which seemed to be more or less accidental, usually amounted to a few tenths of a second of arc, and very rarely to as much as a second of arc, which is equivalent to a linear distance of about 0.001 inch (0.025 mm). Even though discrepancies are the exception rather than the rule, and discrepancies of the magnitude referred to above are extremely rare, nevertheless they cause considerable annoyance when extreme accuracy is desired, for the error of measurement need not much exceed 0.001 mm. It seemed highly desirable definitely to locate, if possible, the cause of the difficulty. In the case of the Crossley star-photographs it seemed for a time as though the cause must be sought for in the large mirror of the telescope. Another alternative was the study of the photographic film itself. Accordingly, in the winter of 1904, at the suggestion of Director Campbell and Dr. Perrine, the writer undertook an investigation of the distortions of the gelatine film.

The principal previous investigations on the distortions of the gelatine film were made by Scheiner, Loewy, Bergstrand, and Ludendorff. Scheiner[2] at first believed he had found a contraction in one co-ordinate and a dilation in the other, and assumed that this distortion was progressive, i. e., proportional to the distance measured. In 1897,[3] however, he says:

> Weitere Erfahrungen haben indessen gezeigt, dass man wahrscheinlich die Verziehungen nicht der gemessenen Strecke proportional setzen darf, sondern dass sie ziemlich localer Natur sind und sich häufig schon auf sehr kurze Strecken hin wieder aufheben.

[1] Thesis in partial fulfilment of the requirements for the degree of doctor of philosophy in the University of California.

[2] *Zeitschrift für Instrumentenkunde*, **11**, 394, 1891.

[3] *Photographie der Gestirne*, p. 119.

Loewy,[1] from a study of an *Eros* plate with multiple exposures, using three images of each of 82 stars, came to the conclusion that distortions of the film introduced an accidental error into the differences $x_n - x_m$ and $y_n - y_m$ which was represented by a probable error of 0".06 (=0.001 mm or 0.00004 inch).

Bergstand[2] investigated two star-plates, and from his results drew the following conclusions: Except near the edges of the plate, the distortions are, in general, not common to large parts of the plates; the affected regions are in the nature of bands or strips, which are not greater than 5 mm, and probably much smaller than this; these strips seem to have a tendency to be oftener parallel to one co-ordinate than to the other. The two plates studied by him seem to show a striking agreement both as to the amounts and trend of the distortions, and he concludes therefore that the distortions cannot always be eliminated by the use of several plates.

Ludendorff[3] investigated two of his star-plates and found that they showed large distortions which extend systematically over a considerable portion of the plates. On both plates he found several neighboring reseau-lines to be curved, the convex side being directly toward the center on one of the plates, and away from the center on the other. In some cases he found the inclination of the reseau-lines to be somewhat changed. The largest relative displacement between two neighboring lines was 10 μ. He states, however, that his endeavor was principally to find plates with strong distortions. It is well to quote some of the additional circumstances to which he calls attention.

> Ganze Gruppen von Platten, welche an demselben Abend oder an naheliegenden Abenden aufgenommen wurden, weisen an demselben Randstriche Krümmungen in demselben Sinne, aber von verschiedenen Betrage auf. Auch kommen mitten unter diesen Platten ganz normale vor. . . . . Auffällig bleibt indessen, dass diese Verzerrungen an Platten, welche aus derselben Zeit stammen, mit solcher Regelmässigkeit auftreten, bei Platten aus anderen Zeiten gar nicht, und dass sie, wenigstens soweit meine Beobachtungen reichen, hauptsächlich einen bestimmten Strich (A 26) und dessen Nachbarstriche betreffen.

[1] "Sur la précision des coordinées des astres . . . . ," Third Memoir, p. 83. in *Bulletin du Comité international permanent pour l'exécution photographique de la carte du ciel*, **3**, 1902.

[2] *Ofversigt af K. Sv. Vet.-Akad. Förhandl.*, 1900, No. 2, p. 38.

[3] *Astronomische Nachrichten*, **162**, 343, 1903.

He explains these facts in the following words:

> Bei näherer Überlegung sieht man indessen, dass es möglich ist, für beide Erscheinungen plausible Ursachen anzuführen. Da die Gitterkopien alle gleichartig in den Kasseten gelegen haben, so wird es sich ganz von selbst ergeben, dass sie sich auch bei allen photographischen Processen in derselben Lage befunden haben. Namentlich beim Trocknen, während dessen die Platten nahezu senkrecht standen, meist eine bestimmte Seite des Gitters die untere, horizontale gewesen sein. Eine nähere Betrachtung der nötigen Manipulationen macht es nicht unwarscheinlich, dass dies der Strich 26 gewesen ist.

He also says that he found numerous cases of local distortions. As an example of these he mentions plate No. 40 on which portions of two neighboring reseau-lines are bent in opposite directions.

From the above outline it will be seen that our knowledge of the nature and amounts of the distortions was quite indefinite. The prevailing opinion in regard to the subject was well stated by Professor H. H. Turner,[1] of Oxford, who is here quoted:

> Even now it can scarcely be said that we know definitely the stage of refinement at which we must begin to expect irregular displacements of the images from distortion of the photographic film; but we have learned that they do not occur in a gross degree, and that other apparatus must be improved before we need turn our attention seriously to errors arising from such a cause.

The more important features of the plan upon which my work was begun were investigations of the effects of (*a*) the position of the plate during the processes of washing and drying, (*b*) the rate of drying, (*c*) abrupt changes in the rate of drying during the process, (*d*) change in the position of the plate while drying, (*e*) hardener. Emulsions on plate-glass were also tried. Jewell's developer was used, and the plates were $3\frac{1}{4} \times 4\frac{1}{4}$ inches (83 × 108 mm) in size, the same as are used with the Crossley Reflector.

FIRST SERIES—EFFECT OF POSITION OF THE PLATE

The first point considered was the effect of the position of the plate during the photographic processes. For this purpose a transit-of-*Venus* reticle was copied by contact, on a series of six plates. A Rochester (ordinary oil) lamp at a considerable distance was used as the source of light, and the exposures were made as nearly alike as possible. This gave images of the reseau-lines clear on a darkened background. The plates were Seed's Gilt Edge No. 27, ordinary

[1] *Observatory*, **27**, 396, 1904.

emulsion. Plates 1, 2, and 3 were kept horizontal (film side up) during development, fixing, washing and drying, and Plates 4, 5, and 6 vertical. Plate 5 was overexposed, and was therefore not used. The remaining five plates were measured on the Stackpole measuring-engine in orientations 0° and 180°. Seventeen intersections of the reseau-lines distributed over an area $3\frac{1}{2}\times 2$ inches were measured on each plate, four settings being made on each intersection. The readings were made to the nearest 0.0001 of an inch, the fourth decimal place being estimated, and in the reductions the means were carried one decimal place farther. In the reduction of Plates 2, 3, 4, and 6 to Plate 1, one of the intersections was used as a center, and the corrections were applied for scale-value, orientation, and center. Table I, in which the letters represent intersections, gives the residuals in units of 0.00001 inch.

TABLE I

SERIES OF PLATES FOR VERTICAL AND HORIZONTAL POSITIONS OF PLATE. RESIDUALS IN UNITS OF 0.00001 INCH (0.00025mm)

Number of Plate	a_x	a_y	b_x	b_y	c_x	c_y	d_x	d_y	e_x	e_y
2	− 7	+ 6	− 6	**+28**	+ 2	+17	+ 4	−13	− 5	+ 1
3	− 2	± 0	− 1	+ 2	− 4	+ 5	+ 7	+ 8	− 1	−11
4	− 6	± 0	+ 7	± 0	+ 8	−16	− 5	+ 7	**−25**	+ 2
6	+13	− 4	**+26**	− 1	− 6	− 5	− 7	− 3	+ 8	+ 6
	l_x	l_y	g_x	g_y	h_x	h_y	i_x	i_y	j_x	j_y
2	+15	− 2	−10	**−23**	+ 4	− 8	+ 8	+ 8	− 4	**+23**
3	− 7	− 1	+ 5	− 5	+ 8	− 3	± 0	+ 2	+ 1	− 6
4	−19	+ 4	**+37**	± 0	− 5	+ 3	− 6	− 8	+ 2	**−23**
6	+13	**+22**	+ 4	+ 4	− 8	+ 9	− 4	− 4	**−37**	+ 8
	k_x	k_y	l_x	l_y	m_x	m_y	n_x	n_y	o_x	o_y
2	− 6	− 6	+ 5	−14	− 3	− 1	**+48**	+ 5	− 8	+ 8
3	+12	+ 6	+12	− 1	− 7	+ 8	− 6	+ 6	+ 4	−10
4	− 4	− 4	−11	**+46**	− 7	− 4	+12	+ 2	− 1	+16
6	− 3	+ 5	− 5	+16	+16	− 3	− 7	−11	+ 3	−15
	p_x	p_y	x Center	y						
2	−15	− 8	+ 3	+ 2						
3	+ 6	+20	− 4	+ 6						
4	+18	+ 3	− 2	− 1						
6	− 8	−14	+ 2	− 7						

In order to obtain values for the mean and greatest errors of measurement, Plate I was measured by two observers, the plate having been removed from the engine in the interval. The mean difference between the two observers for thirty-four co-ordinates is 6.5 and the greatest difference 19, in units of the fifth decimal place. Fifteen of the differences were negative, fifteen positive, and four zero. $[-v]=106$, $[+v]=114$. These differences include, in addition to errors of measurement (of bisection, reading of the scales, and division errors of the scales), differences in personality between the two observers, if such differences exist. It was therefore thought allowable to consider 19 as the greatest error due to measurement alone. Accordingly all residuals over 20 in magnitude (in bold type in Table I) were regarded as being larger than the error of measurement. Omitting these large residuals, the resulting mean residual is ± 6.6. The agreement of this value with the mean error of measurement also tends to justify this course.

The conclusions to be drawn from this series of plates are as follows: It was possible to superimpose the seventeen points measured on Plates 2, 3, 4, and 6 upon the corresponding points of Plate 1, within the errors of measurement, except for occasional large accidental deviations of individual points. Plates 1, 2, and 3 were kept horizontal, and 4 and 6 vertical, during the photographic processes. Therefore, for the size of plates used ($3\frac{1}{4}\times 4\frac{1}{4}$ inches) and the region measured ($2\times 3\frac{1}{2}$ inches) it is entirely indifferent whether the plate be vertical or horizontal during the photographic treatment. A re-examination of the intersections for which large residuals were obtained showed in a few cases that the shift was due to the arrangement of thc silver grains rather than to an actual movement of a portion of the film. In other cases the intersection appeared to be perfectly normal.

SERIES SECOND

The general plan for the second series of plates was as follows:[1]

A. Ordinary commercial plates (Seed 27, Gilt Edge).

I. Uniform rate of drying.

[1] As it was the principal object of this investigation to acquire a more definite knowledge of the nature and magnitude of the distortions that are to be expected under ordinary conditions in the manipulation of photographic plates, extreme conditions (according to the above outline) were avoided.

1. Rapid drying.
   (*a*) By heat.
   (*b*) By draft.
2. Slow drying (in a cool place without draft).
3. When partly dry turn plate on opposite edge and allow drying to continue at the same rate.

II. Change in the rate of drying.
1. Without turning plate over.
2. Turning plate over when changing the rate of drying.

III. Hardener.

B. Same emulsions on plate-glass.

A form, from which artificial-star plates could be printed by contact, was made in the following way. An 8×10-inch clear glass plate was spattered with small drops of drawing-ink. From these, sixteen groups of spots well distributed over the plate, with a total of forty-six images of suitable sizes, were selected, and all the remaining spots rubbed off. This pattern was then photographed on a 5×7-inch transparency plate, the resulting image of the pattern plate being approximately $3\frac{1}{4}\times4\frac{1}{4}$ inches in size. This positive was used as a form with which all the exposures of artifical-star images were made by contact printing. Twenty plates of the same emulsion (Seed 27) were exposed consecutively and as nearly alike as possible, five exposures of seven seconds' duration being made on each plate. The temperature of the room during the exposures was 54° to 57° F. Between exposures the plate was shifted (parallel to the X and Y directions) so that the corresponding images of four of the exposures were at the corners of a square approximately half an inch on each side, and the image of the fifth exposure was at the center of the square. Each plate therefore contained five exposures of the same sixteen groups (forty-six images) of artificial star-disks. The following designations were used: The groups are lettered from a to p inclusive. The images are represented by the letter of the group with a subscript. Usually the subscript numbers were assigned in the order of increasing size of disk. The exposures are lettered α to ϵ, arranged as follows: starting around the square in the X-direction from α, the remaining corners are represented by β, ϵ, and δ; and γ is at the intersection of the two diagonals.

These twenty plates were treated differently in the photographic

TABLE II

Plate No.	Development		Fixing			Washing—(In flowing water)			Drying—(All Vertical)				Remarks
	Time	Temp.	Kind	Time	Temp.	Position	Time	Temp.	Cut edge	Time	Temp.		
	min.			min.			hrs.			hrs.			
1	8	21–17°C.	Plain hypo. with sodium sulphite to prevent oxidation	30	11°C.	Horizontal. Did not rub.	3	9°±C.	down	4	63° F.		
2	8	21–17		30	11	Horizontal. Did not rub.	3	9	down over	4	63		Almost dry when turned over.
3	8	21–17		30	11	Horizontal. Did not rub.	3	9	up over	4	63		
4	8	21–17		30	11	Horizontal. Did not rub.	3	9	up over	4	63		
5	8	21–17		30	12	Horizontal. Rubbed lightly.	2½	9	down	6	52	In dark room	⅜ dry when
									over	1±	75+	In assembly room	turned over.
6	8	21–17		30	12	Horizontal. Rubbed lightly.	2½	9	down	6	52	In dark room	⅜ dry when
									over	1±	75+	In assembly room	turned over.
7	8	21–17		30	12	Horizontal. Rubbed lightly.	2½	9	down	6	52	In dark room	½ dry when
									over	1±	75	In assembly room	turned over
8	8	21–17		30	12	Horizontal. Rubbed lightly.	2½	9	down	6	52	In dark room	¼ dry when
									over	1±	75+	In assembly room	turned over.
9	8	20–16		30	13	Horizontal. Did not rub.	3	9	down	1½	75+	On desk near stove	
10	8	20–16		30	13	Horizontal. Did not rub.	3	9	up	4±	63		Alum bath after washing.
11	8	20–16		30	13	Horizontal. Did not rub.	3	9	down	4±	63		Alum bath after washing.
12	8	20–16		30	13	Horizontal. Did not rub.	3	9	down	4±	63		Alum bath after washing.
13	8	20–16		20	13½	Vertical. Did not rub.	4	9	down	¾	67	Fanned till dry	One half fixed much slower. Cut in film.
14	8	20–16		20	13½	Vertical. Did not rub.	4	9	down	1½	75+	Near stove	
15	8	20–16		20	13½	Vertical. Did not rub.	4	9	up	20±	50–52	Without draft	
16	8	20–16		20	13½	Vertical. Did not rub	4	9	down	20±	50–52	Without draft	
17	8	20–16	Cramer's chrome-alum solution	75	13½	Vertical. Rubbed.	4	9	up	20±	50–52	Without draft	
18	8	20–16		75	13½	Vertical. Rubbed.	4	9	down	20±	50–52	Without draft	
19	8	20–16		75	13½	Vertical. Rubbed.	4	9	down	¾	67	Fanned till dry	
20	8	20–16		75	13½	Vertical. Rubbed.	4	9	down	1½±	75	Near stove	

processes, and constitute the material for the study of Part *A* of the the general plan as outlined above. Table II contains the principal data in regard to their treatment.

Of these plates Nos. 20, 13, and 6 were selected for measurement. They represent a variety of different conditions in the treatment. Plate 20 was fixed in Cramer's chrome-alum fixing solution; Plates 6 and 13 were fixed without the use of any hardener; one-half of Plate 13 fixed clear very much slower than the other half; Plates 13 and 20 were washed in the vertical position, Plate 6 in the horizontal position; Plates 6 and 20 were rubbed lightly with the fingers at the beginning and end of washing; Plate 20 was dried fairly rapidly in a warm room; Plate 13 was fanned briskly until dry; when Plate 6 was partly dry it was turned over and the temperature of drying changed from 52° to 75° F. The remaining plates were kept in reserve, to be measured later if it should be deemed advisable. Exposure γ on Plate 20 was taken as the standard to which the exposures on the same and other plates were reduced. Table III contains the measures of Plate 20γ. The reduction consisted in computing by least squares for each exposure the orientation and center corrections, and then applying these corrections to the individual images. The first half of Table IV gives the residuals (reduced readings on the images of the exposure under consideration minus the readings on Plates 20γ) in units of 0.00001 inch. Column 8 contains the means of columns 2 to 7 inclusive, and may therefore be looked upon as being the errors—both of measurement and of possible distortions—contained in exposure 20γ. Columns 9 to 14 inclusive give the residuals of columns 2 to 7 free from the errors in the standard exposure. Columns 8 to 14 give, therefore, the errors, both of measurement and distortion, for all the exposures for which the measures were reduced, including the standard exposure. Column 8 is in all respects similar to columns 9 to 14.

These residuals do not exhibit any evidence of general distortions. They show that it is possible to superimpose the forty-six images of any one of the exposures upon the corresponding forty-six images of the standard exposure within the errors of measurement, except for occasional large deviations of individual images. In the reductions the only corrections applied to the measures were for orientation

TABLE III

MEASURES OF EXPOSURE 20γ. STANDARD

Image	*X*	*Y*	Image	*X*	*Y*
	Inches	Inches			
a_1	+1.37220	+0.63252	i_1	+0.00312	+0.02350
a_2	+1.40292	+0.65730	i_2	+0.02148	+0.00042
a_3	+1.37908	+0.68480	j_1	+1.22858	−0.39250
b_1	+0.79238	+1.13332	j_2	+1.17052	−0.35050
b_2	+0.75240	+1.13010	k_1	−0.76720	−0.61312
b_3	+0.69948	+1.11008	k_2	−0.78495	−0.63310
c_1	+0.04840	+0.89590	k_3	−0.81718	−0.56308
c_2	+0.02368	+0.84462	l_1	−1.34562	−0.51180
c_3	−0.03320	+0.93892	l_2	−1.33685	−0.58785
d_1	−1.07100	+0.94532	m_1	+1.31190	−1.10922
d_2	−1.03768	+0.99265	m_2	+1.29708	−1.10702
d_3	−1.00698	+0.97450	m_3	+1.32748	−1.15560
d_4	−0.94438	+1.09078	m_4	+1.29845	−1.17382
e_1	−1.70625	+1.08228	n_1	+0.07812	−0.83482
e_2	−1.72230	+1.04370	n_2	+0.04072	−0.82970
e_3	−1.78522	+0.95872	n_3	+0.03955	−0.88841
f_1	+0.68900	+0.37985	o_1	−1.45818	−1.05158
f_2	+0.74265	+0.38090	o_2	−1.49360	−1.03122
f_3	+0.73288	+0.36008	o_3	−1.49638	−1.06692
g_1	−0.63635	+0.33485	o_4	−1.48262	−1.05298
g_2	−0.70440	+0.23180	p_1	−1.69795	−0.51146
h_1	−1.52612	+0.34778			
h_2	−1.44290	+0.33450			
h_3	−1.43722	+0.38050			
h_4	−1.39555	+0.30578			

and center. No scale-correction was needed; i. e., the actual linear distances between the images remained the same within the area covered by the images (3.7×2.8 inches). Several of the images were within $\frac{1}{8}$ inch (3 mm) of the edge of the plate.

A word of explanation is desirable in regard to an apparent systematic trend of the residuals over limited regions of some of the exposures. For example: Near the end of column 13γ eleven residuals of both *X* and *Y* are negative; the first few in column 6γ are positive; the first few of column 20β are negative. On Plate 6 the effect cannot be due to the sudden change in the rate of drying, because part of the affected region was dry before the change was made, while another part was the last to become dry. Although these residuals are in magnitude within the limits of the errors of measurement, they might be mistaken for minute general distortions. Without much doubt, however, their true origin may be found in the varying conditions of illumination and temperature during measurement. The measures

were made during the winter months when the weather conditions were unsettled, and alternate passing of clouds and clear sky produced marked changes in the illumination of the plate. In some cases the effect could be directly traced to this cause. Besides, the large number of images (230) on each plate rendered it impossible to complete the measures in both orientations on the same day. Where a small number of images is to be measured on a plate, constant conditions can usually be secured during the measures.

For Part B of the second series an 8×10-inch plate-glass plate, coated with a film of Seed's 27 ordinary emulsion, was used. In each corner of the plate five exposures were made in the same manner as on Plates 1 to 20. The plate was developed, fixed, washed, and dried in the ordinary way, and then cut into four parts. These four parts were numbered from 21 to 24, inclusive. The γ exposure of Plate 21 was measured and reduced to 20γ, by applying corrections only for orientation and center. It was here also found possible to superimpose the forty-six images of 21γ upon the corresponding images of 20γ within the errors of measurement, except for a few individual larger residuals. In so far as we are justified in drawing conclusions from this one plate, we may say that in the matter of distortions of the film plate-glass offers no advantages over the ordinary commercial plates.

Through this one plate-glass plate a partial connection is also made between $3\frac{1}{4}\times4\frac{1}{4}$-inch and 8×10-inch plates. The absence of any evidence of general distortions on Plate 21 would tend to show that the greater extent of the film on the larger plate does not introduce a sagging of the film due to its greater total weight (i. e., a sort of cumulative effect).

A large number of spectrograms of high and low dispersion were examined for evidences of distortion, and the results obtained are entirely in accord with the conclusions drawn from the investigation of the artificial-star plates. No cases of general distortions were found, i. e., none of the kind with which this investigation is concerned.[1] A considerable number of local distortions were found. These were confined in each case to one or a few adjacent spectrum

[1] Occasionally a plate will show blisters which are visible to the unaided eye These blisters are caused by the omission of some necessary precaution in the treatment of the plate, usually by too high a temperature of one of the solutions or by too great a difference in the temperatures of the various solutions. As the gelatine (before it is treated with a hardener) dissolves at 90° F., the temperature of the solutions should

TABLE IV

Image	Residuals: Image on Plate, Minus Corresponding Image on Plate 20γ (in units of 0.00001 inch)								Corre	
	Plate 20α		20β		20δ		20ε		13γ		6γ		Errors in 20γ		20α	
	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y	X	
a_1	± 0	−10	−26	− 7	±14	− 2	+ 1	+ 4	− 1	+ 5	+19	+19	+ 1	+ 1	− 1	
a_2	+34	−13	−15	−23	± 0	− 8	+ 3	− 9	Defective		+17	+ 1	+ 7	−10	+27	
a_3	+18	− 6	− 7	+11	+14	+16	+12	+17	+ 2	+ 1	+28	+ 1	+11	+ 7	+ 7	
b_1	+23	+ 8	− 9	+21	+16	+29	− 4	+46	− 9	+44	+29	+55	+ 8	+34	+15	
b_2	+11	−35	−23	+ 2	+ 6	+10	− 8	+25	+ 8	+13	+19	+30	+ 2	+ 7	+ 9	
b_3	+27	− 1	−12	+32	+ 6	+28	− 4	+45	− 1	+39	+32	+51	+ 8	+32	+19	
c_1	+28	−19	+ 3	+ 7	+20	+21	+19	+19	+ 7	+ 6	+35	+26	+19	+10	+ 9	
c_2	+ 2	+ 1	− 5	− 2	+ 7	− 5	+ 1	− 9	+13	+54	+35	+10	+ 9	± 0	− 7	
c_3	+ 1	− 5	−11	+ 5	+14	+17	− 6	+17	− 8	+ 3	+23	+12	+ 2	+ 8	− 1	
d_1	+ 6	−23	± 0	−21	+ 8	+16	+ 6	+ 4	+ 1	+ 8	+23	+13	+ 7	± 0	− 1	
d_2	+15	−13	+ 8	± 0	+13	− 3	− 3	+ 4	+ 4	+ 7	+ 7	+15	+ 7	+ 2	+ 8	
d_3	+18	− 2	− 7	+15	+ 5	+ 5	− 1	+ 1	+ 3	+15	−18	+ 9	± 0	+ 7	+18	
d_4	+14	−12	− 1	+11	+ 3	+ 1	−10	+21	+10	+ 9	+29	+16	+ 7	+ 8	+ 7	
e_1	−25	+39	+ 7	+10	−15	+16	+ 1	− 3	− 6	+15	−23	+18	−10	+16	−15	
e_2	−32	+15	+ 2	+16	−21	+24	+ 6	− 1	−14	+18	−38	+32	−16	+17	−16	
e_3	−25	−46	−14	+38	−34	+13	− 9	−43	−12	− 3	−31	−14	−21	− 9	− 4	
f_1	+21	+ 1	+ 3	+ 2	− 3	+19	−14	+17	− 6	−15	− 3	+ 7	± 0	+ 5	+21	
f_2	+19	+23	+ 1	+13	+13	+50	− 2	+32	+ 1	− 1	+20	+10	+ 9	+21	+10	
f_3	+10	+56	−18	+49	+14	+77	+ 1	+78	−17	+49	−23	+58	− 6	+61	+16	
g_1	+11	−41	± 0	− 2	− 6	−16	+14	− 6	+13	−33	− 1	− 1	+ 5	−16	+ 6	
g_2	+11	−13	− 8	− 5	+12	+ 3	+ 2	± 0	+ 7	−16	− 5	−11	+ 3	− 7	+ 8	
h_1	− 4	−11	− 8	− 7	+ 3	− 6	−15	+ 9	+21	− 5	+ 9	−11	+ 1	− 6	− 5	
h_2	+ 4	− 7	+ 5	+ 4	+ 9	+ 3	− 9	+22	+12	− 1	+ 5	+ 4	+ 4	+ 4	± 0	
h_3	± 0	− 2	+ 4	+10	+ 5	+16	+ 2	+17	+ 6	− 1	+19	−12	+ 6	+ 5	− 6	
h_4	+ 6	+ 1	− 3	+ 6	−17	+22	−18	+23	+15	+ 1	+ 8	+ 5	− 1	+10	+ 7	
i_1	−14	+ 3	− 5	+ 7	− 5	+12	−37	+21	− 6	− 5	−21	+ 5	−15	+ 7	+ 1	
i_2	+ 4	− 2	+ 1	+19	+ 7	+10	+ 2	+14	+ 6	− 9	−14	+ 6	+ 1	+ 6	+ 3	
j_1	+21	+10	−11	+11	+10	− 2	− 8	+30	−10	− 7	v faint		± 0	+ 8	+21	
j_2	+11	± 0	−10	+ 8	− 2	+23	− 9	+21	+ 7	+10	−13	−16	− 3	+ 8	+14	
k_1	−13	−12	± 0	−20	+ 5	−17	− 9	−16	−18	−15	+ 5	+ 6	− 5	−12	− 8	
k_2	− 1	− 3	− 1	+14	+ 7	+15	−23	− 4	+ 9	+10	± 0	+16	− 1	+ 8	± 0	
k_3	+13	+ 2	+25	+ 5	+10	+19	−20	+ 4	+23	+ 1	± 0	+18	+ 8	+ 8	+ 5	
l_1	− 5	+ 1	+ 9	− 5	− 7	+14	− 9	− 9	{ Film		+ 4	−12	− 2	− 2	− 3	
l_2	− 1	−17	+ 7	−24	− 4	−11	+ 4	+ 9	{ torn		−11	± 0	− 1	− 9	± 0	
m_1	+10	−21	−12	−19	+ 3	−24	+ 2	−33	−15	−30	v faint		− 2	−25	+12	
m_2	+13	− 1	+ 9	+ 4	+13	− 5	+12	− 7	− 3	−21	−24	+ 5	+ 3	− 4	+10	
m_3	+25	± 0	− 1	± 0	+12	−15	+ 7	−23	− 6	−14	−19	± 0	+ 3	− 9	+22	
m_4	+21	+ 5	− 4	+25	+ 6	− 2	+11	− 8	−12	−21	−33	− 9	− 2	− 2	+23	
n_1	+16	− 2	+ 5	+10	+10	+ 7	+ 9	+36	− 9	−12	+ 5	+10	+ 6	+ 2	+10	
n_2	+12	+ 7	−16	+ 5	− 6	+ 9	− 9	+29	− 8	− 3	+37	+ 5	± 0	+ 9	+12	
n_3	+15	+ 8	+ 4	− 2	− 1	− 1	+ 2	+14	− 3	−14	+19	−15	+ 6	− 2	+ 9	
o_1	− 4	−21	+31	+20	+ 4	−23	+ 3	−14	−13	−39	+ 1	−29	+ 3	−20	− 7	
o_2	−16	− 7	+ 3	+ 5	−16	−12	− 4	−24	−19	−25	− 8	−22	−10	−14	− 6	
o_3	−30	+19	− 3	− 7	− 4	−24	− 3	−25	−32	−32	−16	−24	−15	−20	−15	
o_4	− 2	+ 8	− 3	− 1	−19	−17	−16	−28	−17	−17	− 1	−15	−10	−11	+ 8	
p_1	− 9	−16	− 2	− 5	− 8	+ 7	− 8	−10	+17	− 5	− 8	+11	− 3	− 3	− 6	

CORRECTED FOR ERRORS CONTAINED IN THE STANDARD EXPOSURE, i.e. IN 20γ

n Y	20α X	20α Y	20β X	20β Y	20δ X	20δ Y	20ε X	20ε Y	13γ X	13γ Y	6γ X	6γ Y
1	− 1	−11	−27	− 8	+13	− 3	± 0	+ 3	− 2	+ 4	+18	+18
10	+27	− 3	−22	−13	− 7	+ 2	− 4	+ 1	Defective		+10	+11
7	+ 7	−13	−18	+ 4	+ 3	+ 9	+ 1	+10	− 9	− 6	+17	− 6
34	+15	−26	−17	−13	+ 8	− 5	−12	+12	−17	+10	+21	+21
7	+ 9	−42	−25	− 5	+ 4	+ 3	−10	+18	+ 6	+ 6	+17	+23
32	+19	−33	−20	± 0	− 2	− 4	−12	+13	− 9	+ 7	+24	+19
10	+ 9	−29	−16	− 3	+ 1	+11	± 0	+ 9	−12	− 4	+16	+16
0	− 7	+ 1	−14	− 2	− 2	− 5	− 8	− 9	+ 4	+54	+26	+10
8	− 1	−13	−13	− 3	+12	+ 9	− 8	+ 9	−10	− 5	+21	+ 4
0	− 1	−23	− 7	−21	+ 1	+16	− 1	+ 4	− 6	+ 8	+16	+13
2	+ 8	−15	+ 1	− 2	+ 6	− 5	−10	+ 2	− 3	+ 5	± 0	+13
7	+18	− 9	− 7	+ 8	+ 5	− 2	− 1	− 6	+ 3	+ 8	−18	+ 2
8	+ 7	−20	− 8	+ 3	− 4	− 7	−17	+13	+ 3	+ 1	+22	+ 8
16	−15	+23	+17	− 6	− 5	± 0	+11	−19	+ 4	− 1	−13	+ 2
17	−16	− 2	+18	− 1	− 5	+ 7	+22	−18	+ 2	+ 1	−22	+15
9	− 4	−37	+ 7	+47	−13	+22	+12	−34	+ 9	+ 6	−10	− 5
5	+21	− 4	+ 3	− 3	− 3	+14	−14	+12	− 6	−20	− 3	+ 2
21	+10	+ 2	− 8	− 8	+ 4	+29	−11	+11	− 8	−22	+11	−11
61	+16	− 5	−12	−12	+20	+16	+ 7	+17	−11	−12	+17	− 3
16	+ 6	−25	− 5	+14	−11	± 0	+ 9	+10	+ 8	−17	− 6	+15
7	+ 8	− 6	−11	+ 2	+ 9	+10	− 1	+ 7	+ 4	− 9	− 8	− 4
6	− 5	− 5	− 9	− 1	+ 2	± 0	−16	+15	+20	+ 1	+ 8	− 5
4	± 0	−11	+ 1	± 0	+ 5	− 1	−13	+18	+ 8	− 5	+ 1	± 0
5	− 6	− 7	− 2	+ 5	− 1	+11	− 4	+12	± 0	− 6	+13	−17
10	+ 7	− 9	− 2	− 4	−16	+12	−17	+13	+16	− 9	+ 9	− 5
7	+ 1	− 4	+10	± 0	+10	+ 5	−22	+14	+ 9	−12	− 6	− 2
6	+ 3	− 8	± 0	+13	+ 6	+ 4	+ 1	+ 8	+ 5	−15	−15	± 0
8	+21	+ 2	−11	+ 3	+10	−10	− 8	+22	−10	−15	v faint	
8	+14	− 8	− 7	± 0	+ 1	+15	− 6	+13	+10	+ 2	−10	−24
12	− 8	± 0	+ 5	− 8	+10	− 5	− 4	− 4	−13	− 3	+10	+18
8	± 0	−11	± 0	+ 6	+ 8	+ 7	−22	−12	+10	+ 2	+ 1	+ 8
8	+ 5	− 6	+17	− 3	+ 2	+11	−28	− 4	+15	− 7	− 8	+10
2	− 3	+ 3	+11	− 3	− 5	+16	− 7	− 7	{ Film	}	+ 6	−10
9	± 0	− 8	+ 8	−15	− 3	− 2	+ 5	+18	{ torn	}	−10	+ 9
25	+12	+ 4	−10	+ 6	+ 5	+ 1	+ 4	− 8	−13	− 5	v faint	
4	+10	− 3	+ 6	+ 8	+10	− 1	+ 9	− 3	− 6	−17	−27	+ 9
9	+22	+ 9	− 4	+ 9	+ 9	− 6	+ 4	−14	− 9	− 5	−22	+ 9
2	+23	+ 7	− 2	+27	+ 8	± 0	+13	− 6	−10	−19	−31	− 7
2	+10	− 4	− 1	+ 8	+ 4	+ 5	+ 3	+34	−15	−14	− 1	+ 8
9	+12	− 2	−16	− 4	− 6	± 0	− 9	+20	− 8	−12	+37	− 4
2	+ 9	+10	− 2	± 0	− 7	+ 1	− 4	+16	− 9	−12	+13	−13
20	− 7	− 1	+28	+40	+ 1	− 3	± 0	+ 6	−16	−19	− 2	− 9
14	− 6	+ 7	+13	+19	− 6	+ 2	+ 6	−10	− 9	−11	+ 2	− 8
20	−15	+39	+12	+13	+11	− 4	+12	− 5	−17	−12	− 1	− 4
11	+ 8	+19	+ 7	+10	− 9	− 6	− 6	−17	− 7	− 6	+ 9	− 4
3	− 6	−13	+ 1	− 2	− 5	+10	− 5	− 7	+20	− 2	− 5	+14

lines, and very rarely covered an area as much as $\frac{1}{4}$ mm square. The greatest displacement observed amounted to 0.02 mm, which on the Crossley star-photographs is equivalent to about one second of arc, and on the spectrograms taken with the one-prism spectrograph of the Lick Observatory to about 80 km radial velocity per second (for the $H\gamma$ region). Such large displacements as this are, however, extremely rare. The great majority of the displacements observed are less than one-fourth of this amount.

Some of the characteristic shapes of the distorted lines are: a sine-curve, a question-mark, an irregular crinkle, an abrupt bend, a gradual bend which is sometimes shared by two and occasionally by three adjacent spectrum lines, while the lines immediately on either side of the distorted ones are perfectly straight.

The distortions seem to be principally of two different kinds. In one kind, aside from the bending or twisting, the appearance of the line is normal as regards width, sharpness of the sides, and structure of the grain. In this case the most plausible explanation for the distortion is an actual movement of a minute portion of the film. In the other kind the distorted shape of the line seemed to be due in some cases to the peculiar arrangement of the silver grains, and in others to local differences in the sensitiveness of the film. The occasional non-uniformity in the sensitiveness of the film is usually very local, but at times it extends over a considerable portion of the plate. Probably an extreme case of the latter was shown on one of my lantern slides, on which a non-sensitive streak, varying in width from 0.1 to 0.05 inch (2.5 to 1.25 mm), extends more than half-way across the plate. Very rarely also one of the distortions would have the appearance of having been caused by slight movements of a minute area of the film immediately around a grain of impurity.

SUMMARY OF RESULTS

1. For the size of the plates used ($3\frac{1}{4}\times4\frac{1}{4}$ inches) it was found to be entirely indifferent whether the plate be vertical or horizontal during development, fixing, washing, and drying.

2. Within the range of the observations, hardener, the rate of drying, and changes in the rate of drying and in the position of the

not be allowed to become higher than 75° F. The distortions which were considered in this investigation were those which occur when ordinary (good) care is taken in the treatment of the plate.

plate during the process of drying introduced no general distortions of the gelatine film.

3. Local distortions were found on artificial-star plates and on spectrograms. These distortions were confined in each case to an area equal to a small fraction of a square millimeter. The largest lateral displacement found at any point in the distorted area was 0.02 mm, while the great majority were less than one-fourth of this amount. Some of these displacements are several times as large as the errors of measurement, and their possible effects must be taken into account where great accuracy is desired.

4. These distortions seem to be principally of two different kinds: one was due to an actual movement of a minute portion of the film, the other was an apparent shift of the image due to the peculiar arrangement of the silver grains or to local differences in the sensitiveness of the film.

5. The results obtained from one plate-glass plate showed no advantages of the plate-glass over the ordinary commercial plates in the matter of distortions of the film.

6. If the results obtained in this investigation for small plates be found to apply with equal force to larger plates, it will follow that the assumption which is the basis for the use of the reseau is not well founded. The assumptions involved, briefly stated, are as follows: First, general distortions exist; second, they differ in different parts of the plate; third, they may be assumed to be linear within the squares of the reseau, i. e., over a stretch of 5 mm or more. The supposed advantages of the reseau over the method of referring all the measures to a common center rest entirely upon the validity of these three assumptions. If the reseau can be dispensed with, there will be a saving of the labor involved in making the large number of settings on the reseau-lines and in the reductions of the measurements.

Throughout these investigations on photographic distortions I had the valued advice and assistance of Dr. Perrine, who had long been interested in the problem, and it is a pleasure to acknowledge my indebtedness to him. It should also be said that fully half of the measures of the first series were made by him.

LICK OBSERVATORY
UNIVERSITY OF CALIFORNIA
May, 1907

Reviews

Atlas Stellarum Variabilium. Series IV, containing those variable stars which are included in the limits of the *B. D.* charts in declination and magnitude. By J. G. Hagen, S. J., Director of the Vatican Observatory. Berlin: Felix L. Dames, 1907. Two volumes, charts and catalogue. 4to. 100 Marks.

Hagen's great atlas of variable stars is now well known and quite indispensable to the observer in this field. The present series completes the original plan, though extensions are projected by the author and in part ready for the press. This series is the largest of all, containing 100 fields, the variables being adapted for observation with apertures of 8 to 16 cm This series is therefore the most useful one to possessors of small telescopes.

The charts resemble those in Series I, II, and III, in that they are all on the same scale and that each contains one variable at the center; but differ from them in several particulars. The inner red square is one degree on a side, therefore on half the scale of the previous series. This square shows all the *B. D.* stars and such fainter ones, down to magnitude 11, as are needed for identification or for comparison stars when the variable is near minimum. The outer parts of the chart contain certain *B. D.* stars down to magnitude 8–9. In regard to the accuracy of the positions, the introduction states that the brighter stars are taken from the best catalogues, chiefly those of the *Astronomische Gesellschaft.* The fainter stars were located, partly by original observations, partly from Harvard photographs, and some from the *B. D.* catalogue. As a check, the reviewer compared the twenty stars in the inner square of the chart for *U Pegasi*, with a photo-

Hagen No.	Errors	
	R. A.	Dec.
2.....	.....	−0′.38
6.....	−1ˢ.2	.....
10.....	−6.5	.....
11.....	−1.6	.....
14.....	−3.4	+0.61
15.....	+2.2	.....
16.....	.....	+0.30
19.....	−4.3	.....

graph. After allowing for the distortion in right ascension caused by the projection used, the co-ordinates of six stars were in error by more than one second of time. Errors greater than $0''.25$ in declination were found for only three stars. For the twenty stars the mean errors were only $\pm 11^{s}$ and $\pm 0''.1$, respectively.

The catalogue sheets give in the usual form the data needed for the reduction of the observations. Estimates of the brightness of the comparison stars were made in grades by Hagen and Hisgen, but the method of reduction to magnitudes is peculiar to this series, being obtained by a graphic process, based on photometric magnitudes furnished by Professor Pickering for a part of the stars in each field. These Harvard magnitudes are given in the fourth column of the catalogue sheets. They are mostly from unpublished observations, and therefore cannot, at present, be reduced to the system of either of the Harvard catalogues.[1] The column of notes gives, for the brighter stars, the Potsdam colors and magnitudes rounded to the nearest 0.1.

This division of the *Atlas* makes a fitting introduction to a new series of publications from the Vatican Observatory, and places the astronomical world under renewed obligations to the author.

J. A. PARKHURST

YERKES OBSERVATORY
May, 1907

FABRY AND BUISSON'S *Wave-Lengths of Standard Lines.*

In accordance with resolutions adopted at the Oxford meeting of the Solar Union in 1905, Fabry and Buisson[2] have recently measured the wave-lengths of eighty-four standard lines in the region of the spectrum comprised between λλ 6500 and 3600. The green line of mercury, produced by a Cooper-Hewitt lamp, was chosen as the primary standard. The value of this line was determined by careful comparisons with the red and green lines of cadmium measured by Michelson and Benoit. From this line were then deduced the values of the other standard lines produced by the passage of a current of from 6 to 3 amperes at a voltage of 120 between iron electrodes 8 mm in diameter, the method of comparison being that hitherto used by Perot and Fabry, but photographic instead of visual. The interferences (fringes at infinity) were caused by two plane-parallel silver-on-glass mirrors. The spectrum was produced by a plane-grating used with auto-collimation.

[1] See Müller and Kempf, *Potsdam Photometrische Durchmusterung, General Katalog*, p. xxii.

[2] *Comptes Rendus*, **143**, 165, 1906.

The values given below are for wave-lengths in air at 15° C. and at a pressure of 760 mm; and each is the mean of several measures on different plates. The discordance between independent measures rarely amounted to one part in a million. One of the lines belongs to manganese, which is present as an impurity in commercial iron. In the region about λ 5800 it was necessary to supplement the iron lines with four nickel lines, in order that the interval between any two standard lines should not exceed 50 Å. U. The wave-lengths of Rowland and of Kayser and Runge may be reduced to the same scale by dividing by 1.00003.

3606.687	4375.939	5012.075	5658.837
3640.396	4427.318	5049.829	5709.398
3677.634	4466.558	5083.346	*Ni* 5760.845
3724.385	4494.576	5110.418	5763.015
3753.620	4531.159	5127.367	*Ni* 5805.213
3805.351	4547.857	5167.495	*Ni* 5857.761
3843.266	4592.661	5192.364	*Ni* 5892.883
3865.531	4602.947	5232.960	5934.685
3906.486	4647.439	5266.570	5952.740
3935.823	4678.858	5302.319	6003.040
3977.750	4707.290	5324.198	6027.060
4021.877	4736.788	5371.500	6065.494
4076.645	4753.147	5405.782	6137.701
4118.556	4789.660	5434.532	6191.570
4134.689	*Mn* 4823.524	5455.618	6230.733
4147.682	4859.759	5497.523	6265.148
4191.446	4878.229	5506.785	6318.030
4233.619	4903.327	5535.420	6335.344
4282.411	4919.009	5569.634	6393.613
4315.093	4966.107	5586.772	6430.860
4352.745	5001.883	5615.660	6494.994

S. B. B.

A GENERAL INDEX TO THE ASTROPHYSICAL JOURNAL

The preparation of an index to the first twenty-five volumes of this Journal, covering the twelve and one-half years from January, 1895, to June, 1907, is now under consideration. Such an index would doubtless prove of great convenience to the workers in astrophysics and to libraries. The possibility of its publication will depend upon the number of advance orders received. If 200 subscriptions are obtained, the index can probably be issued at a cost of about $1.50; if 300 advance orders should be given, the work will certainly be undertaken, with the expectation of its publication in the autumn of 1907, and the price will probably be somewhat less than $1.50.

All subscribers and librarians who would purchase such an index, if issued, are therefore requested to notify the editors at once by postcard of the number of copies for which they will subscribe.

Address, Editors of the Astrophysical Journal, Williams Bay, Wisconsin, U. S. A.

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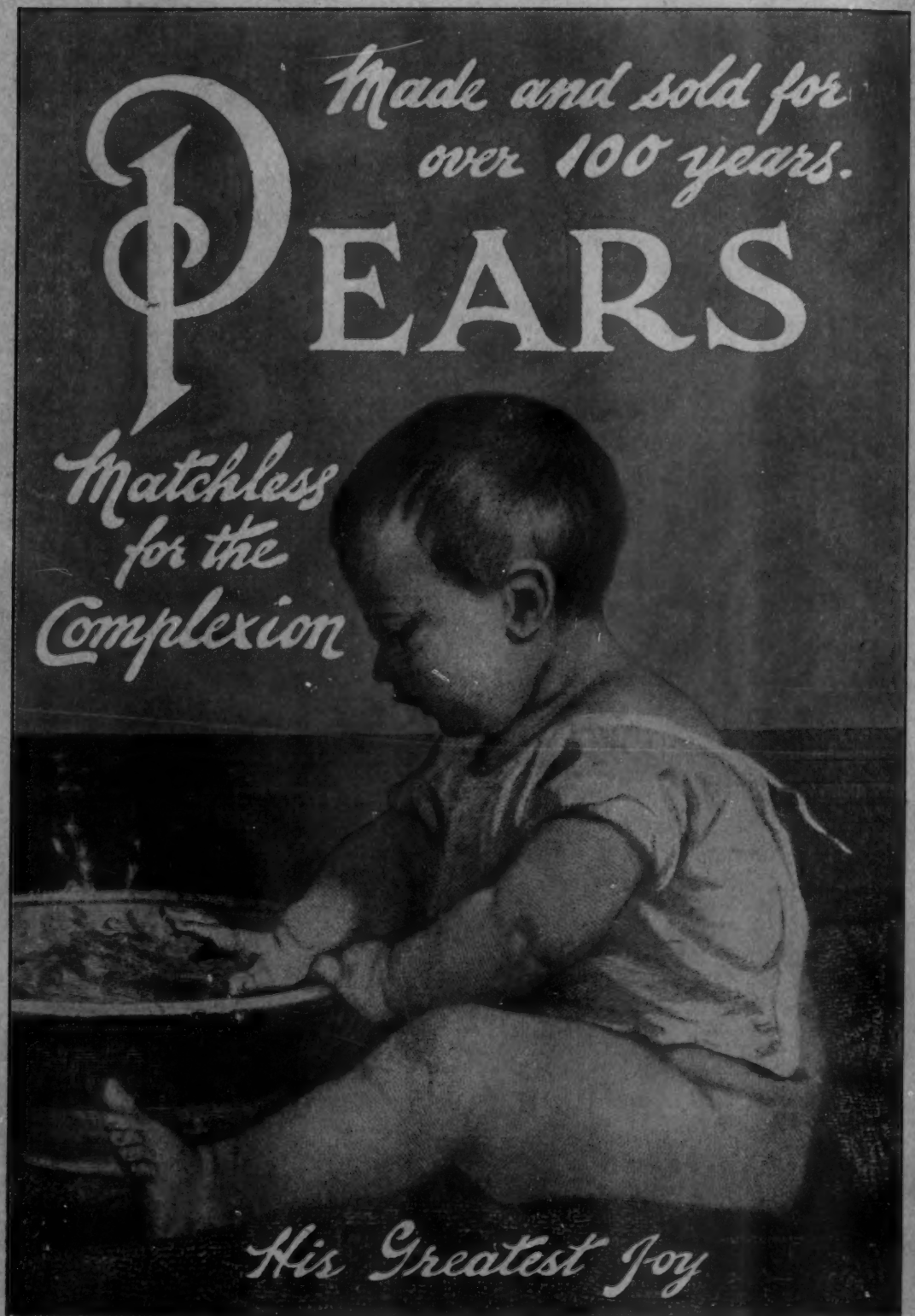

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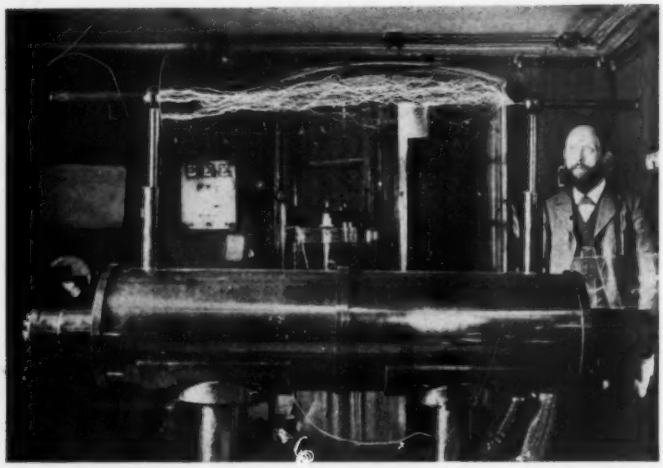

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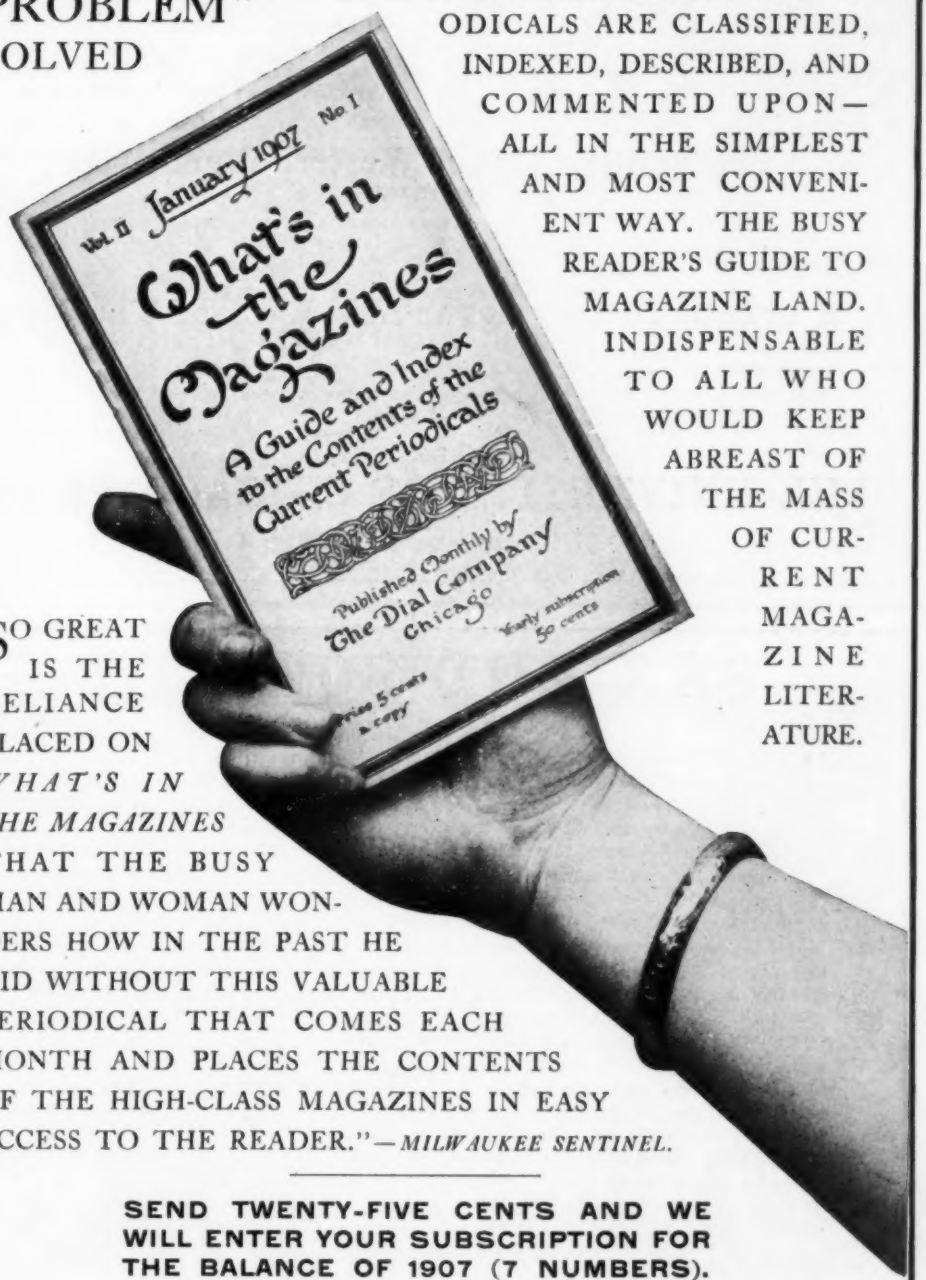
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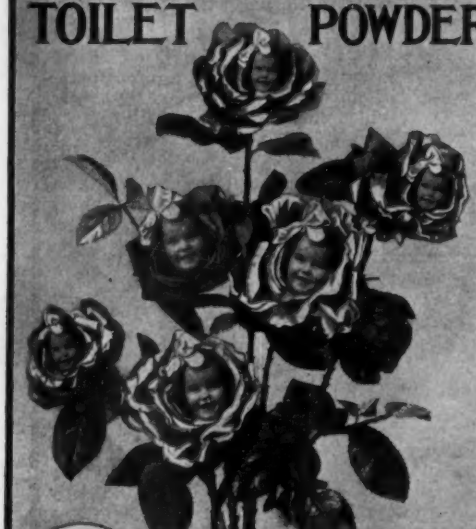

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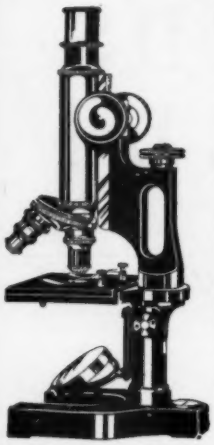

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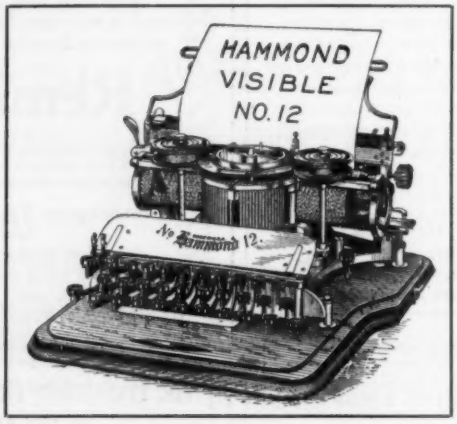

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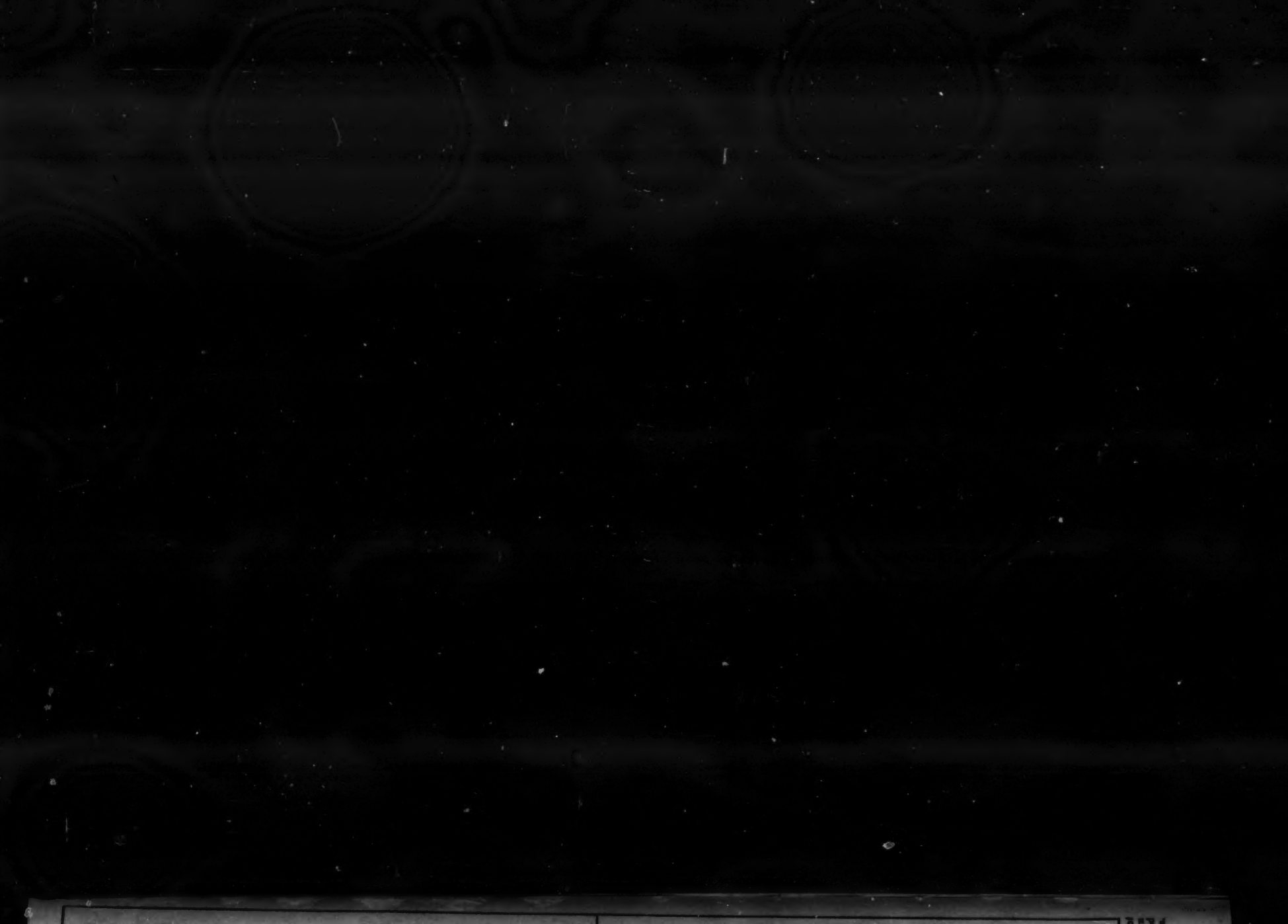
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